Correctness and Speed of Dyslexics and Non-dyslexics on the Four Mathematical Operations

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by

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ABSTRACT

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This research describes an investigation of the correctness and speed of response that dyslexic children and matched controls perform on mathematical calculations involving addition, subtraction, multiplication and division.

The participants were 120 boys divided into three age bands ranging from 9:5 – 11:4, 11:5 – 13:4 and 13:5 – 15:4 years of age of whom 60 were dyslexic and 60 non-dyslexic.

Two sets of 144 multiplication sums, two sets of 75 addition and 75 subtraction sums and one set of 144 division sums were presented. In the case of multiplication and division, the numbers ranged from 1 to 12; in the case of addition and subtraction two separate effects were examined, viz. sums involving high and low addends / subtrahends in combination with sums that did and did not cross the ten barrier.

Results showed that dyslexics in all age bands took longer and made fewer correct responses than non-dyslexics on all four mathematical operations. The performance of the younger dyslexics was differentially disadvantaged when compared to non-dyslexics and older dyslexics on speed and correctness. The dyslexics performed less well when no obvious algorithm was available to them and when answering questions that involved crossing the ten barrier. The dyslexics were less able, in all age bands, than non-dyslexics to respond instantaneously. The overall trend with both groups was an increase in scores with age; however on some occasions the dyslexics in the old age band did not perform as well as those in the middle-age band suggesting practice and automaticity effects. The order of difficulty (from greatest to least) of the four mathematical operations for dyslexics, as judged by number of correct responses was: division, subtraction, multiplication and addition. For the non-dyslexics this was: subtraction, division, multiplication and addition. For speed the order for both the dyslexics and non-dyslexics was: subtraction, addition, division and multiplication.

Additional behaviours such as use of fingers, other bodily movement, audible vocalization relating to the question and other audible vocalization were found to characterise the performance of the dyslexics.

Possible reasons for these differences are discussed and it is argued that if a mathematical task involving any of the four operations is hard for a non-dyslexic, it is likely to be *especially* hard for a dyslexic. The research substantiates particular theories of dyslexia. Practical implications are suggested for parents, teachers and examiners concerned with dyslexic children and adults.

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CHAPTER 1

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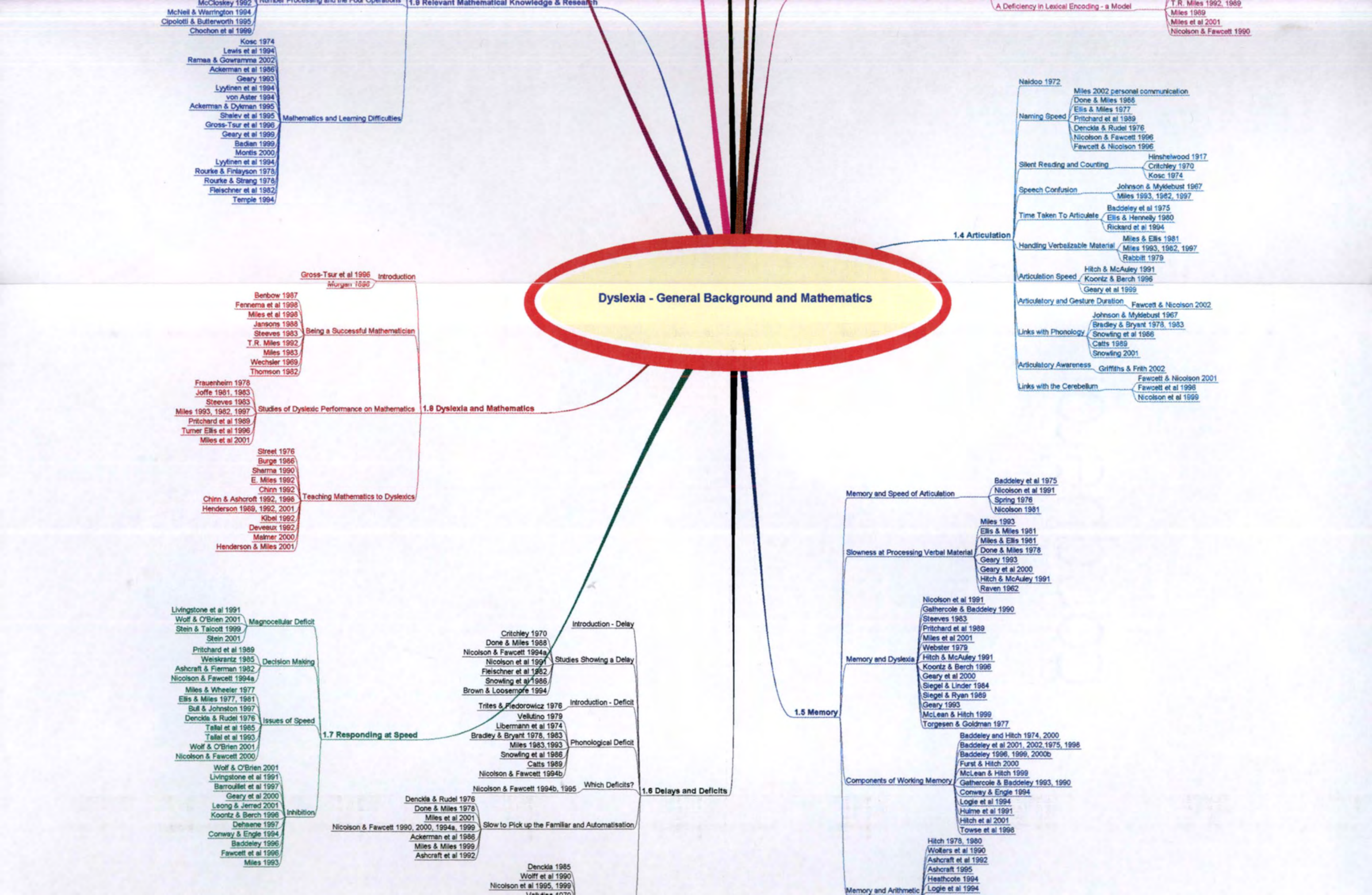

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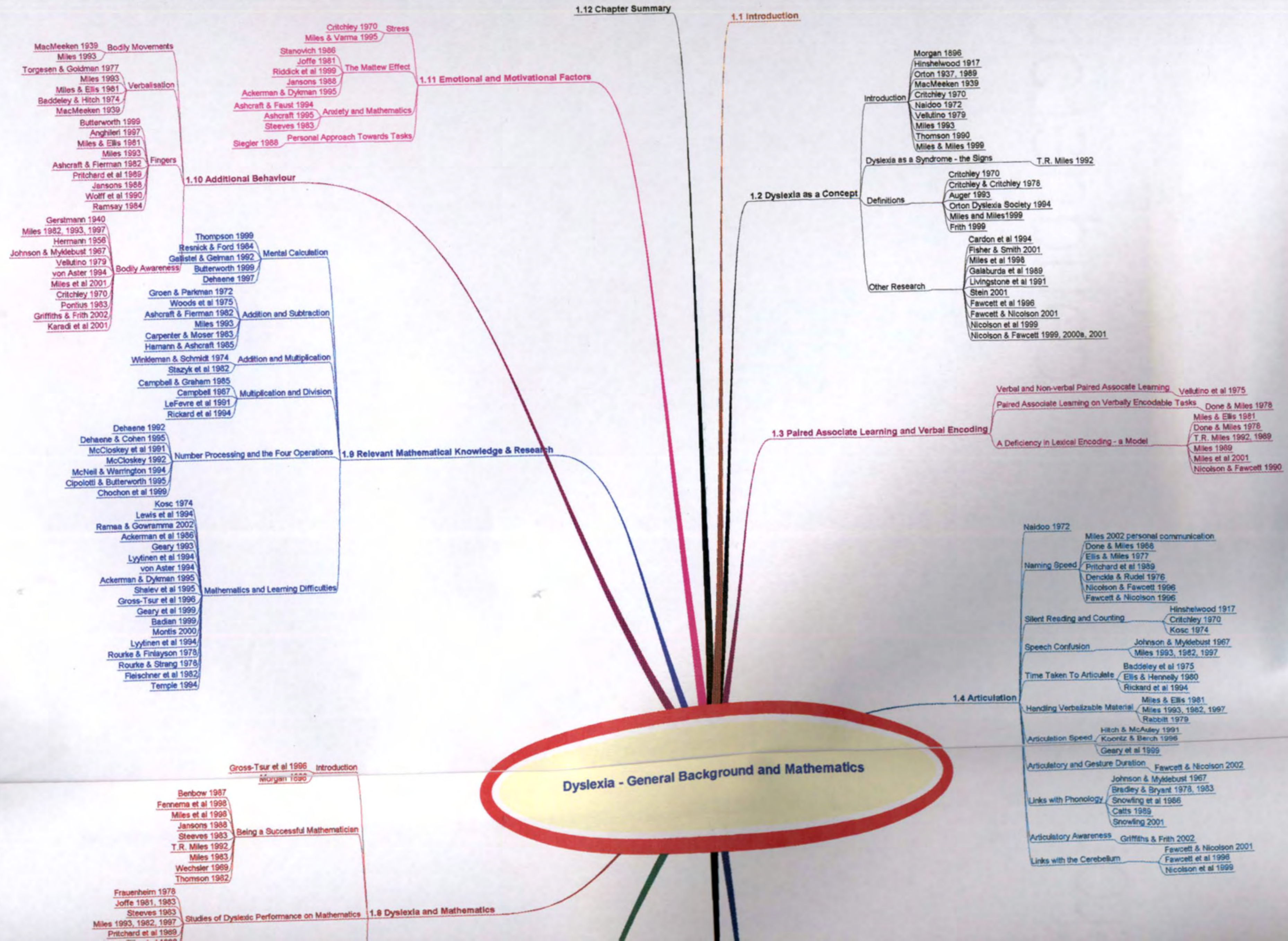

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1.1 Introduction

This chapter is presented in three parts:

- Part 1 – gives perspectives on dyslexia with signs and definitions followed by details of current and relevant theories of dyslexia.
- Part 2 – provides a review of literature on dyslexia and mathematics with further information on related mathematical knowledge and research .
- Part 3 – supplies details of other aspects of dyslexics' performance. This includes additional behaviours that characterize the performance of dyslexics, such as bodily movements, verbalization and use of fingers. Bodily awareness, emotional and motivational factors are also presented.

This chapter introduces but does not elaborate on the anatomical and physiological aetiology of dyslexia, or on phonology. It seeks to provide a conceptual frame of reference in which the empirical studies are grounded. Emphasis has been placed on a review of literature that is relevant to and provides a context for the issue of correctness and speed in dyslexia and mathematics.

The Mind Map (folded page) entitled 'Dyslexia – General Background and Mathematics' presents the main headings and authors referred to (in order) in this chapter.

Part 1: Perspectives on Dyslexia

1.2 Dyslexia as a Concept

1.2.1 Introduction

It is not the intention of the author to review every aspect of dyslexia, but to concentrate on those aspects that have particular pertinence to the topic of this thesis. Notwithstanding this the reader is referred to general review articles should they so wish.

From an historical perspective, Morgan (1896), a general practitioner in Sussex, made one of the earliest recorded observations of a dyslexic student. He described the case of a 14-year-old boy named Percy who had difficulty with reading and spelling. A Glasgow eye surgeon named Hinshelwood (1917) wrote extensively about cases that exhibited 'congenital word blindness', a term which he attributed to Kussmaul who had first used the phrase in 1877. For more details of early accounts of dyslexia, see Orton (1937, 1989), MacMeeken (1939), Critchley (1970), Naidoo (1972), Vellutino (1979), Miles (1993), Thomson (1990) and Miles and Miles (1999).

1.2.2 Dyslexia as a Syndrome – the Signs

T.R. Miles (in Miles and Miles, 1992, p.1) wrote that 'Dyslexia can usefully be described as a "syndrome" – that is, a pattern of signs which regularly go together: any one of these signs on its own would be of no specific significance, but if several of them co-occur in the same individual they take on a meaning which none of them would have in isolation'.

Some of the indications of dyslexia include: difficulty with reading acquisition, spelling problems, despite tuition, which can last into adulthood, distinguishing left from right and a weak memory for 'disconnected items in series, such as the months of the year or visually or auditorily presented digits' (T.R. Miles, in Miles and Miles, 1992, p.1). Such difficulties may be accompanied by strengths in art and design, engineering, visualization and associated mechanical skills and logic.

Other signs of dyslexia include difficulties with: slow speech development, repeating polysyllabic words accurately without getting tongue-tied, name finding, written confusion over 'b' and 'd', keeping simple rhythm, saying multiplication tables without losing the place, learning to tell the time, time keeping and awareness of time, number order, e.g. units, tens, hundreds, and mathematical symbols which can be confused, e.g. + and × signs.

1.2.3 Definitions

To define dyslexia has been a great challenge, especially in such a way as to gain general acceptance. This is particularly so because a wide range of specialist fields are now involved in research on dyslexia and each views the subject from their own particular expertise. The five definitions given here range from 1968 to 1999 and illustrate the effect that advances in research have had on our understanding of dyslexia. Despite this, very little mention has been made within the definitions about the difficulties that dyslexics can also experience with mathematics.

It is clear that our understanding of dyslexia has come a long way when considering a definition of dyslexia given at the World Federation of Neurology in 1968: 'A disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence, and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin' (Critchley, 1970).

Critchley and Critchley (1978) offered a revised, improved version of the earlier (1968) definition of dyslexia as:

> A learning-disability which initially shows itself by difficulty in learning to read, and later by erratic spelling and by lack of facility in manipulating written as opposed to spoken words. The condition is cognitive in essence, and usually genetically determined. It is not due to intellectual inadequacy or to lack of socio-cultural opportunity, or to faults in the technique of teaching, or to emotional factors, or to any known structural brain-defect. It probably represents a specific maturational deficit which tends to lessen as the child grows older, and is capable of considerable improvement, especially when appropriate remedial help is afforded at the earliest opportunity. (p. 149)

This definition makes no mention of mathematics or music because little was known about their significance as part of the syndrome of dyslexia at the time.

The British Dyslexia Association has produced several definitions of dyslexia and one by Augur (1993) is presented here:

> '[Dyslexia is] a specific difficulty in learning, in one or more of reading, spelling and written language which may be accompanied by difficulty in number work, short-term memory, sequencing, auditory and/or visual perception, and motor skills. It is particularly related to mastering and using written language – alphabetic, numeric and musical notation. In addition oral language is often affected to some degree'.

With this definition there is an emphasis on practical and educational aspects rather than neurological or cognitive findings.

The fourth definition chosen was written by the Orton Dyslexia Society (1994), which is now known as the International Dyslexia Association (IDA):

> Dyslexia is one of several distinct learning disabilities. It is a specific language-based disorder of constitutional origin characterised by difficulties in single word coding, usually reflecting insufficient phonological processing abilities. These difficulties in single word decoding are often unexpected in relation to age and other cognitive and academic abilities; they are not the result of generalized developmental disability or sensory impairment. Dyslexia is manifested by variable difficulty with different forms of language, often including, in addition to problems of reading, a conspicuous problem with acquiring proficiency in writing and spelling.

This was written with the aim of achieving 'legal status nationwide' in the United States of America for provision of special help (Miles and Miles, 1999).

A more recent definition of dyslexia influenced the focus of the Fifth British Dyslexia Association International Conference at the University of York in 2001. This was written by Frith (1999) who formulated a cohesive definition of dyslexia that sought to enable incorporation of diverse findings:

> Dyslexia can be defined as a neuro-developmental disorder with a biological origin and behavioural signs which extend far beyond problems with written language. At the cognitive level, putative causes of the behavioural signs and symptoms of the condition can be specified. These hypothetical deficits are subject to controversy, but serve as a basis for testable predictions at both the behavioural and biological levels. At all three levels, interactions with cultural influences occur. These influences have a major impact on the clinical manifestation of dyslexia, the handicap experienced by the sufferer, and the possibilities for remediation.

Thus Frith advocates classification of dyslexia at the biological, cognitive and behavioural levels. The framework of this model is capable of accommodating new findings in diverse fields.

1.2.4 Other Research

Other related advances in research that illustrate the breadth of Frith's definition include:

(1) the identification of genes that influence the development of dyslexia (Cardon et al., 1994; Fisher and Smith, 2001). Miles et al. (1998) reported a gender ratio for dyslexia of 4.5 males to 1 female;

(2) anatomical and physiological research – post mortem examinations of five male dyslexic brains revealed 'focal areas of cellular disorganisation ... ectopic neurons (abnormal placement) ... abnormal architecture ... increased numbers of neurons and connections in the symmetrical language areas studied ... unexpectedly uniform absence of left-right asymmetry in the language area' (Galaburda et al., 1989);

(3) the magnocellular deficit (Livingstone et al., 1991; Stein, 2001);

(4) the cerebellar deficit (Fawcett et al., 1996, Fawcett and Nicolson, 2001; Nicolson et al., 1999, Nicolson and Fawcett, 1999, 2000a, 2001);

(5) cognitive accounts – paired-associate learning, lexical encoding deficiency, connectionist modelling, an automatisation deficit and phonological deficit;

(6) the behaviour of dyslexics on: mathematical, motor, memory and articulatory tasks.

During the course of the literature review, reference will be made to aspects of dyslexia found to be relevant to the performance of dyslexics when carrying out mathematical tasks.

1.3 Paired Associate Learning and Verbal Encoding

Verbal encoding is of particular relevance to the research because the performance of the dyslexics has been shown to be particularly adversely affected by the processing of material, such as digits, which is verbally encodable (see Vellutino et al, 1975). The main research methodology included the use of digits in the experiments.

1.3.1 Verbal and Non-verbal Paired Associate Learning

Vellutino et al. (1975) compared the performance of poor and normal readers on verbal and non-verbal paired-associate learning tasks. The subjects were boys and girls in fourth, fifth and sixth grade. In the non-verbal task the subjects were asked to remember specific oral responses, such as a high hum or a 'smooch' (lips puckered), and to pair these with simple designs. There were five such pairings to learn. The non-verbal tasks therefore required visual-auditory associations to be formed. In the two verbal tasks, four nonsense syllables were presented vocally (WIB, PEX, MOG, YAG) and were paired with four pictorial representations (that were cartoon-like and included parts of familiar animals). The same nonsense syllables were also paired with four lots of unknown script each with three letter-like figures. The verbal tasks therefore required visual-verbal associations to be formed. The results showed that the poor readers performed as well as the normal readers on the non-verbal association task. However, the poor readers had greater difficulty than the normal readers in both verbal association tasks and their errors, on saying the nonsense syllables, included a greater number of substitutions that were 'real' words (semantic substitution). The researchers emphasised in the findings that the association difficulties of the poor readers might be 'a manifestation of a basic dysfunction in the labeling process'.

Therefore where learning involves a verbal component the poor readers are particularly at risk.

1.3.2 Paired Associate Learning on Verbally Encodable Tasks

Done and Miles (1978) tested the claim that 'dyslexic subjects are inferior to non-dyslexic subjects at remembering a sequence of items only when those items need to be verbally encoded'. The performance of 18 dyslexic subjects (mean age 13:2 years) was compared to 18 control subjects matched on age. All subjects were of at least average intelligence in all experiments. Three experiments were conducted. In the first experiment 5, 6 and 7 items each of digits, pictures, and nonsense shapes were presented sequentially. The subject had to demonstrate that they could remember the order of presentation of each. One point was awarded for each item indicated in the correct order in which it had been presented giving a maximum possible score of 54. The results for this experiment showed that as the items became more easily encodable the scores for both groups improved, such that the greatest scores for both groups were achieved on digits then pictures and lastly nonsense shapes. However this advantage was 'differentially greater in the non-dyslexic group'. No significant difference was found between the groups on the nonsense shapes condition. The greatest difference in mean scores between the groups was on the digits condition (10.8) and digits were the most verbally encodable of the three conditions. The differentiation between the groups was greatest on this condition. Thus dyslexics were shown to be at a distinct disadvantage when having to remember verbally encodable material.

Experiment 2 included a comparison of 15 dyslexic subjects (mean age 15:3 years) with 15 age-matched controls. The subjects were asked to demonstrate their retention of tachistoscopically presented sequences of seven digits. The subjects had to delay their retention response by between 5 and 20 seconds. During this delay the subjects performed an articulatory suppression task (saying 'the' repeatedly). Two conditions also required the subject to respond immediately or 20 seconds after stimulus offset without articulatory suppression. The results showed that under the articulatory suppression conditions the two groups did not differ appreciably on retention. Thus the conclusion reached showed that 'interference by means of a task which involves verbal retention affects the controls more than it affects the dyslexic subjects'.

In experiment 3, ten dyslexic subjects (mean age 14:3 years) and ten age-matched controls were paired. The control subjects had been chosen because of a high score on digit sequencing and a similar score on nonsense shape sequencing (in relation to their allotted dyslexic partner) in preliminary tests. Each subject followed a six-part procedure as follows:

(1) Test 1 – five nonsense shapes were presented sequentially and the subjects were asked to demonstrate their memory of the sequence immediately.
(2) Paired-associate learning task – the shapes were presented again but this time they were paired with a meaningless CVC trigram presented auditorily. The subjects had to call out the CVC trigram when its corresponding shape pair was presented. The correct CVC trigram was then presented as confirmation. This procedure was repeated until each subject had reached the criterion of completing two consecutive trials without error. Then, the subjects had to name 56 presentations of the shapes when shown to them on a card.
(3) Test 2 – the subjects were asked to remember the sequence of the nonsense shapes as in the first condition of this experiment.
(4) One week later re-learning of paired associates took place, including the card presentation.
(5) Test 3 – subjects again had to remember the sequence of just the nonsense shapes.
(6) Test 4 – the subjects said the names of the shapes.

Points were allocated for items remembered in the correct order.

The results showed that the greatest difference in the mean scores of the dyslexics and the controls was for Test 4. Of the four tests, this was the only one with a significant group difference ($p < 0.01$). Thus 'when labels are acquired for nonsense shapes the differentiation between dyslexic and non-dyslexic subjects in memory for sequence tests will reappear'.

The results for the paired-associate learning task in procedure (2) showed that the dyslexics needed a significantly larger number of trials before reaching criterion level. The controls needed between 6 and 17 trials whereas the dyslexics needed between 17 and 48 trials (apart from one dyslexic who required 8 trials). Further, the results indicated a correlation between rapid paired associate learning and memory span for digit sequences and score for verbal recall of the sequence of shapes (Test 4).

Done and Miles (1978) concluded that they had confirmed the initial hypothesis whereby dyslexics are inferior to non-dyslexics when remembering item sequences that are verbally encodable.

1.3.3 A Deficiency in Lexical Encoding – a Model

That dyslexics have difficulty acquiring and retrieving nameable material led Miles and Ellis (1981) to propose that 'dyslexic subjects display a limitation at the level of lexical encoding'. They described a model to explain lexical encoding whereby each individual has an internal lexicon (dictionary) 'which provides standards against which incoming stimuli can be matched'. The term 'encoding' indicates a coding process for matching. A deficiency in lexical encoding implies a difficulty in 'activation of entries in the lexicon'. When applied to dyslexia, tasks involving verbalisation will be the most difficult and consequently verbal material will be assimilated slowly. In experiment 3 (Done and Miles, 1978) lexical encoding had been required to match names to nonsense shapes. The dyslexic subjects had needed many more trials than the controls in order to learn the associations. This was one example of a deficiency in lexical encoding. Another example is given in confusion for left and right, which is often experienced by dyslexics. Left and right cause uncertainty because they have 'fluctuation referents', for example a fireplace in a room may be on the right if the person is facing in a particular direction, but it may be on the left when being approached from another direction. The words 'left' and 'right' therefore lack consistency for lexical encoding. Difficulties over left and right are seen in mathematics (T.R. Miles, in Miles and Miles, 1992) when using the four operations, for example division, like reading, begins on the left whereas the other operations 'are required to be started on the right'.

The mathematical difficulties experienced by dyslexics are '"of a piece" with their other difficulties' (Miles, 1989). 'They may have high reasoning ability but – since this is what dyslexia involves – they are invariably weak at the acquisition and retrieval of nameable material, including the nameable material which is needed in mathematics'. T.R. Miles (in Miles and Miles, 1992) proposes that the ability to respond immediately or automatically to a mathematical sum can be thought of as having 'immediate access to the appropriate entry' in the lexicon. Miles and Ellis (1981) refer to the dyslexic tendency to show a weakness at tables, saying the months of the year and seasons in order and recalling digits presented auditorily. Taking the model of a lexical encoding deficiency, it is supposed that 'when a unit is "fed" into the system the relative deficiency in the forming of the lexical code, coupled, of course, with normal decay rate, makes difficult the representation not only of the units themselves but of the relationship between them'. This is exemplified when dyslexics lose their place when reciting their tables or ask where they have got up to or switch into the wrong table when giving sequenced multiplication facts. Miles and Ellis (1981) report that some dyslexics make a request to only say the products in a table rather than say, for example, 'one seven is ..., two sevens are ..., etc.' Another example of a lexical encoding deficiency is shown in the tendency for dyslexics to use their fingers and make marks on paper when counting. Fingers or marks take the place of a 'unit' in the lexical encoding mechanism, which act as reminders that will not 'run away'. 'The mechanism is therefore freed for the activation of other lexical code associations and there is thus avoidance of what would otherwise be an impossible overload'. Thus 'doing, real or imagined, is a substitute for naming'.

Miles et al. (2001) included comments made by judges concerning likely difficulties that dyslexics would encounter on a variety of mathematical questions. The judges showed concern over whether the dyslexics would have 'experienced' certain concepts or vocabulary. Miles et al. emphasised the importance of language being 'registered' by the dyslexic and that it was possible that registering of mathematical terminology and vocabulary would be a challenge, especially where 'unfamiliar words are not being brought into association with other things in their experience'. Thus the dyslexics would need more 'exposures' to names for them to be remembered. Direct links were made in this paper, between the theory of paired-associate learning and automaticity with the statement 'It is presumably part of the same limitation that dyslexics require more exposures to the same stimulus than non-dyslexics before their responses become automatic (Nicolson and Fawcett, 1990)'.

From the preceding research the following aspects were considered in this thesis: the performance of dyslexics on verbal tasks that involve labelling, memory for items that need to be verbally encoded such as digits, paired-associate learning, lexical encoding, speed of assimilation of verbal material, acquiring and retrieving nameable material, learning multiplication table facts and automaticity of response on some mathematical tasks.

1.4 Articulation

To articulate is to speak clearly and distinctly. Articulation may be in response to stimuli, naming, speaking as a way to rehearse information, to aid memory and to communicate one's thoughts. Naidoo (1972) recognised that dyslexic children were 'slow in learning to speak and to understand speech'.

1.4.1 Naming Speed

Miles (2002, personal communication) postulates that:

> The central problem for dyslexics is that they are slow at dealing with rapidly changing stimuli. In that case the mechanisms for converting these stimuli into a form where they take on symbolic significance will be inefficient. Thus dyslexics will take longer to identify and name symbolic material – letters, numerals, diacritical marks, punctuation marks, etc.

Done and Miles (1988) investigated the speed with which dyslexics articulated the names of pictures of familiar objects. Sixty-five pictures, for example 'giraffe', 'bicycle', were presented to 16 dyslexic boys and 16 age-matched controls of mean age 14:6 years who were asked to name them as quickly as they could. Their response latencies were recorded. In addition, a preliminary investigation had been conducted on 101 children between 2 years and 5:11 years to determine the age of acquisition of each of the 65 words. The results showed that there was a correlation of 0.71 between response latency and age of acquisition for the dyslexic group. The dyslexics were consistently slower in response latency than the controls and the conclusion reached was: 'It can be argued ... that the typical dyslexic will on average be 10.8 months later than his non-dyslexic peer in the age at which he acquires a particular word'. This claim enabled a greater understanding of typical difficulties experienced by older dyslexics, such as: absorbing less information than controls matched on spelling-age with visual presentation of digits (Ellis and Miles, 1977) and having less multiplication number facts available (Pritchard et al., 1989). As a 'consequence of the long response latencies in word finding' Done and Miles (1988) surmised that dyslexics, compared to controls, would:

(i) have less time to notice the details of how a word is spelled
(ii) can name fewer auditorily presented 'digit-stimuli' per unit time, and
(iii) can name fewer visually presented 'digit-stimuli' per unit time
(iv) cannot hold in working memory as many names (e.g. months of the year) when these have to be arranged in order, since this requires the retention of symbolic material over time ...
(v) they acquire fewer number facts since, because of the need for more 'exposures', they can make less effective use than non-dyslexics of the opportunities for acquiring them.

In another study, Denckla and Rudel (1976) found that they were able to distinguish dyslexics from non-dyslexics because they took longer to name numbers (2, 6, 9, 4, 7), letters (p, o, d, a, s), colours (red, green, black, blue, yellow) and objects (comb, key, watch, scissors, umbrella). These four groupings are listed from quickest to slowest and this order was the same for all children taking part.

Both the Dyslexia Early Screening Test (DEST) by Nicolson and Fawcett (1996) and the Dyslexia Screening Test (DST) by Fawcett and Nicolson (1996) include a subtest called Rapid Naming. This was included because dyslexics are worse at naming at speed than non-dyslexics.

1.4.2 Silent Reading and Counting

Hinshelwood (1917) referred to a case of a 10-year old girl with reading difficulties who appealed to her memory of speech movements when attempting silent reading. He suggested that the learning of poetry is enhanced when the poem can be read out loud, for here 'there is a simultaneous appeal to three centres – the auditory, speech movements, and the visual'.

Critchley (1970) wrote of the difficulties experienced by the dyslexic child when reading out loud. In addition to interpreting the text, the onerous task of producing correct diction also needed to be achieved. When reciting generally, '... special attention is paid to the sound impressions of the words and the interval between them'. A dyslexic preference was indicated for silent reading that included habitual subvocalisation, for example silent movement of the lips and other muscles used for articulation, this being in contrast to the absence of whispers and movements of highly skilled readers performing true silent reading.

Košč (1974) investigated silent counting by using a test of successively subtracting 7 from 100 on children with mathematical difficulties. This test made it possible to '... disclose disorders of counting silently' particularly when subtracting over tenths, for example '91, 90, 89'. Košč used the term 'ideognostic dyscalculia' to describe difficulty on this test (see 1.9.6).

1.4.3 Speech Confusion

Johnson and Myklebust (1967) recognised the importance of observing when a child finds it difficult to say the number that he wants when reading numbers aloud or performing an oral calculation, despite recognising the correct number when he hears it and being aware that he has said it incorrectly. They used the term 'reauditorization' to describe this. Whilst Johnson and Myklebust were not specifically writing about dyslexia, Miles (1993) noted that dyslexics are liable to become 'tied up' when asked to repeat certain words, such as 'statistical' and 'philosophical'. These words are included as the 'Polysyllables' sub-item of the Bangor Dyslexia Test (Miles, 1982, 1997).

1.4.4 Time Taken To Articulate

Baddeley et al. (1975) showed that memory span was inversely related to word length and was based on the number of words that a subject could read in approximately 2 seconds. Thus time taken to articulate words was an important factor for memory span. Similarly Ellis and Hennelly (1980) found that digit span in Welsh was significantly smaller than that in English because Welsh digits take longer to articulate (on average 385 ms per digit) than English digits (on average 321ms per digit). It was proposed that 'number-name word length will also affect the ease of mental calculation'. Where translation was required from one language to another, this resulted in a reduced memory span. Translation can occur in mathematics where in order to answer a division problem, knowledge of multiplication number facts are used (Rickard et al., 1994). It may be possible that this act of translation reduces memory span.

1.4.5 Handling Verbalizable Material

Miles and Ellis (1981) proposed a model that suggests that we are:

> equipped with an internal lexicon or dictionary which provides standards against which incoming stimuli can be matched. The energy changes which stimulate the receptors (eyes, ears, etc.) are assumed to be represented in the nervous system in the form of engrams or traces, and lexical encoding is the name of the process by which 'codes' (that is, representations of relevant features of these traces) are matched to entries in the lexicon. (p. 217)

As a consequence of a deficiency in activation of entries in the lexicon, 'tasks which involve verbalisation' would be the most difficult for dyslexics. This deficiency would be evident whenever verbalisable material is handled, for example when speaking words which are phonemically confusable (e.g. tongue-twisters). One such example occurred when a student exclaimed, 'I have got my backet on jack-to-front' for the intended phrase 'I have got my jacket on back-to-front' (personal experience of the author). Confusions are found when reciting multiplication tables and writing teen numbers such as 'sixteen' as 61 because the order of writing is at variance with the order in which the number is said (Miles, 1993). The rate of speaking and reading is crucial especially where 'material which is later to be lexically encoded is superimposed upon material at present being lexically encoded' (Miles and Ellis, 1981, p. 228). The Polysyllables item in the Bangor Dyslexia Test (Miles, 1993; Miles, 1982, 1997) illustrates this point. If the polysyllabic words are said too quickly, dyslexics 'are at risk of saying the syllables of the word in the wrong order' (Miles, 1993, p. 194).

Rabbitt (1979) argued generally that to achieve a combination of greatest speed and accuracy when responding, some sort of control process was responsible for 'tracking' the optimum response time band beyond which errors would start to occur, thereby enabling the maintenance of a 'safe' rate of responding. An important factor for success was the ability to estimate time accurately; otherwise 'overshooting' and 'undershooting', around the band of time considered to be 'safe', would occur with consequent responses that were too fast or too slow.

For those whose lexical representation is lacking, hesitations, use of alternative strategies, articulatory confusions and rate of response are a consequence.

1.4.6 Articulation Speed

Hitch and McAuley (1991) found that a group of children with specific arithmetical learning difficulties (ALD) (having normal intelligence and reading attainment) were slow at counting from 1 to 20, a finding that has potential depletory effects on the acquisition of arithmetical skills and their usage. Two possible reasons given were slow articulation or a difficulty in accessing number representations in long-term memory.

Likewise Koontz and Berch (1996) also found that a group of children with ALD displayed slow naming latencies, for both digits and letters. The ALD children, like the above study, had a lower digit span than suitably matched controls, which was attributed to 'a slower articulatory rate for maintaining the correct serial order of any kind of verbal information'.

Geary et al. (1999) measured articulation speed using triads of one-digit number names, common one-syllable words and one-syllable nonwords. The participants were first graders who were classified as: mathematically disabled (MD), reading disabled (RD), a combination of MD/RD disabled and a normal group. The participants had to say each practised triad as quickly as possible two times in a row. A stopwatch measured articulation speed. It was found overall that those with low reading achievement scores had slower articulation speeds than those with average or better reading scores. Moreover, 58% of the RD and MD/RD group were slow processors of the one-digit number names as compared to 35% of the MD and normal group combined (more able readers). One of the main findings was that the RD and MD/RD group showed 'slow articulation for familiar words but average or fast articulation of nonwords'. The long-term representation of familiar words facilitates encoding into the phonological loop (see 1.5.4), with the apparent effect of speeding articulation. The results reinforce the view that children with poor reading achievement 'have difficulties accessing semantic information from long-term memory, although it is not known whether slow articulation speeds will predict later arithmetic-fact-retrieval problems' (Geary et al., 1999).

1.4.7 Articulatory and Gesture Duration

Fawcett and Nicolson (2002) confirmed that dyslexics show a reduced speed of articulation as well as an indication of reduced speed of motor planning. They compared the performance of 13-year-old and 16-year-old dyslexics matched with normally achieving children on age and IQ. Fawcett and Nicolson recognise that articulation is a particularly complex motor skill and presents as 'a major challenge for children with language-based and/or motor-based deficits in dyslexia'. The experimental design involved two tasks: single gesture production (/p/, /t/ and /k/) and compound gesture repetition (/ptk/). A measure of articulatory duration was taken as the measure of time from the onset to the offset for the first gesture. Gesture duration was found by taking 'the mean time from onset of articulation to reset of articulation of the next gesture', thus enabling 'planning duration' (inter-gesture pauses) to be ascertained. The participants were asked to take a deep breath and repeat the tasks one at a time as fast and as steadily as possible. Speech was recorded by computer and analysed using software that enabled the sound stream to be analysed visually. The results showed that the dyslexics performed worse than the same age controls on all of the tasks set, but age effects were not significant. Thus dyslexics have 'persistent and severe problems in speeded articulation on both production and planning of gestures...that deficits are not simply error-based, but can be traced to slow articulation of the individual gestures /p/, /t/ and /k/. Moreover, for the children with dyslexia, the gesture duration was 30–50% longer than the basic articulation time'. Of the dyslexic children 71% (12 out of 17) were impaired on 2 out of 4 tasks (/t/, /p/+, /t/+ and /k/+, where + refers to the gesture duration measure) compared with 6% (1 out of 15) for the controls.

1.4.8 Links with Phonology

Johnson and Myklebust (1967) claimed that dyslexic children do not always have a disturbance in mathematics. Their reasoning was that when learning to read, links must be made between the sequence of letters seen with the sequence of sounds but when learning number symbols (e.g. '2') 'only one visual symbol is related to the spoken word'.

Bradley and Bryant (1978) identified difficulties in auditory organisation as a potential cause of reading backwardness. They compared children who were of normal intelligence who had an average reading skill of 18 months or more behind chronological age with reading age matched controls (who were on average over three years younger) on a sound identification task. Of four monosyllabic words presented, one was the odd word out and the other three shared a sound in common (an opening, middle or final phoneme). A 'startling' difference was found between the groups in favour of the controls, particularly where the first letter was different in the odd word out. The controls also outperformed the children with poorer reading skill on production of rhyming words thus confirming a difficulty with categorising sounds. A further study (Bradley and Bryant, 1983) reinforced the view that 'Children who are backward in reading are strikingly insensitive to rhyme and alliteration'.

A study on the processing of speech by dyslexics chosen alongside age-matched and reading-ability matched controls was conducted by Snowling et al. (1986). The outcome showed that:

> Dyslexic children performed as well as controls when repeating high-frequency words, but they had difficulty relative to CA-controls with low frequency words and relative to both CA- and RA-controls when repeating nonwords ... these results suggest that dyslexics have difficulty with nonlexical procedures (including phoneme segmentation) involved in verbal repetition. (p. 489)

The implications of this research are that new word learning (equivalent to nonsense words initially) will be compromised. Snowling et al. (1986) made links between poor verbal memory difficulties shown by dyslexics and weak accessing of phonological word codes.

Catts (1989) proposed that a deficit in encoding of phonological information in memory is responsible for preventing disabled readers from utilising phonological detail leading to speech production errors. Faulty outputting of phonological information may also cause speech production errors. Consequently, dyslexics may be less able to convert lexical information into a 'sequential sound based code'.

The phonological deficit hypothesis continues to be supported by evidence (Snowling, 2001). Variation seen in reading processes is explained by the individual severity of the child's phonological deficits, which can be compensated for by 'visual memory, perceptual speed and print exposure'. Dyslexics 'come to the task of reading with poorly specified phonological representations in the context of a more general delay in oral language development'.

1.4.9 Articulatory Awareness

Griffiths and Frith (2002) hypothesised that 'information about articulatory movements for specific phonemes is less accessible to dyslexics because of a deficient phonological processing system'. Their research included adult dyslexics of mean age 21.67 years who were compared to non-dyslexics matched on age who attended the same universities. An articulatory awareness task was set that required the subjects to listen to a phoneme and then identify the schematic drawing of a sagittal section of the face that represented the articulation of the phoneme. On this task the dyslexics were significantly weaker than the non-dyslexics. Additional tasks were set that showed that the dyslexics were less accurate on spoonerisms, took longer to name digits and also objects and had lower digit span scores.

1.4.10 Links with the Cerebellum

The cerebellum is involved in 'the control of independent limb movements and especially in rapid, skilled movements'. Mild motor difficulties are attributed to cerebellar impairment, including articulatory fluency, since articulation is 'our most complex motor skill' (Fawcett and Nicolson, 2001).

Cerebellar impairment has been proposed to cause lack of articulatory control in dyslexics leading to phonological deficits. It is claimed that '... cerebellar impairment provides a natural causal explanation of phonological difficulties and of reading, writing and spelling problems that are the critical measures for dyslexia' (Fawcett et al., 1996).

> [A cerebellar deficit] leads to difficulties in acquisition and automatisation of elementary articulatory skills and auditory skills (and hence to difficulties in phonological processing), together with visual skills such as eye movement and letter recognition, and that these difficulties in turn lead to the established early problems in learning to read and spell – a complete route between neurological substrate, elementary cognitive difficulties, and the high-level cognitive skill of reading. (Nicolson et al., 1999, p. 1662)

The role of the cerebellum in other behavioural signs of dyslexia is given in section 1.6.7.

The main conclusions of this section informing the research are that dyslexics can be adversely affected by specific aspects of articulation such as naming and counting speed, confusing speech, taking time to articulate – both on speed of articulation and motor planning, and processing verbalizable material. The causal role of phonology difficulties, articulatory awareness and the cerebellum are presented and discussed.

1.5 Memory

The literature on memory is extensive and only theories and research that are relevant to dyslexia and arithmetic are included.

1.5.1 Memory and Speed of Articulation

Faster articulation rate is associated with higher memory span (Baddeley et al., 1975). Dyslexics have been shown to have persistent problems with articulatory fluency into their mid-teens, sufficient to account for slight deficits found on memory span (Nicolson et al., 1991). Indeed Spring (1976) attributed weak memory span to slow speech-motor encoding in dyslexics and Nicolson (1981) attributed the developmental increase in memory span in 8-, 10- and 12-year-old children to an increase in mean reading rate, taken as how many words could be read in two seconds.

1.5.2 Slowness at Processing Verbal Material

Miles (1993) proposed that dyslexics have difficulty in recalling digits presented auditorily, both in the forwards and reverse conditions, due to a slowness at 'processing symbolic verbal material'. Tasks that require verbalisation place the dyslexic particularly at risk and this forms a central tenet of the lexical encoding deficiency in dyslexics (Ellis and Miles, 1981; Miles and Ellis, 1981). An experiment by Done and Miles (1978) showed that nameable stimuli (arrays of five, six and seven digits) were serially recalled less well by dyslexics than age-matched controls. This was in contrast to minimal differences between the groups on the recall of non-nameable nonsense shapes. Thus 'dyslexic subjects are inferior to control subjects at remembering a sequence of items only when those items need to be verbally encoded ... there are grounds, therefore for claiming that an important characteristic of dyslexia is some kind of limitation in the mechanisms of STM'. 'STM' refers to short-term memory. In experiment 3, Done and Miles (1978) presented 10 dyslexic subjects of mean age 14:3 years with a paired-associate learning task (PAL) whereby nonsense-shape stimuli were each paired with an auditorily presented meaningless CVC trigram. Their performance was compared to 10 age-matched controls and it was found that 9 out of the 10 dyslexics needed significantly more trials than the controls

($p < 0.01$) to reach the criterion on the PAL task. Furthermore it was predicted that '... when labels are acquired for nonsense shapes the differentiation between dyslexic and non-dyslexic subjects in memory for sequence will reappear'.

In relation to arithmetical tables, a weakness in learning these is thought to be 'of a piece' (Miles and Ellis, 1981) with the dyslexic difficulty with recalling the months of the year and seasons in order as well as recall of digits presented auditorily. 'The hypothesis of a lexical encoding deficiency suggests that when a unit is "fed" into the system the relative deficiency in the forming of a lexical code, coupled, of course, with normal decay rate, makes difficult the representation not only of the units themselves but of the relationship between them' (Miles and Ellis, 1981, p.235).

Geary (1993) and Geary et al. (2000) suggested that a slow counting speed is likely to have the effect of poor representation of basic mathematical facts in long-term memory. Children with mathematical disability (MD) retrieve a low number of correct and incorrect facts from memory and display a high error rate and unsystematic retrieval speeds because of working-memory deficits (Geary, 1993).

Hitch and McAuley (1991) showed that children with specific arithmetical learning difficulties tended to count more slowly than normally achieving controls and to have lower auditory digit spans, despite both groups being matched on the Raven's Coloured Progressive Matrices (Raven, 1962). This led the researchers to suggest that counting span difficulties reflected less capacity in working memory thereby affecting the temporary storage of numbers with ongoing processing during simple calculation.

1.5.3 Memory and Dyslexia

Nicolson et al. (1991) specifically studied the links between working memory and dyslexia and replicated experiments conducted by Gathercole and Baddeley (1990) with additional testing on articulation rate on words of differing lengths. Nicolson et al. compared two dyslexic groups (aged 11 and 15 years) with three non-dyslexic groups (aged 8 years – matched for reading age, 11 and 15 years) of comparable IQ.

The subjects were tested on the following:

(1) phonological discrimination – subjects were asked to repeat words that included 36 pairs of single syllable words and 36 pairs of single syllable nonwords. One-third of the pairs were identical, one-third differed by one fricative/affricative feature (e.g. fuse versus views) and one-third differed by a nasal or plosive feature (e.g. cub versus cup);

(2) voice onset time – the subject had to say a known common word as fast as possible when a light flashed on the computer screen. Words of varying length were used and latency data were obtained for voice onset;

(3) nonword repetition – the subject had to repeat nonwords of varying syllable length (2, 3, 4 or 5);

(4) memory span – the subject had to recall the order of a list of words of increasing length (two words, three words, four words and so on) until two consecutive failures were made. Single syllable words were used and grouped according to their phonological similarity (bat, cap, cat, pan, pram, tap) or dissimilarity (bus, clock, hand, horse, girl, spoon);

(5) articulation rate – the subject had to repeat a given word five times and duration was measured. Words used were the same as for the voice onset test.

The results were as follows: the older dyslexics performed slightly worse (not significantly) than their age-matched controls and similarly to the reading age matched controls across the range of tasks. The younger dyslexics performed 'significantly worse than that of their chronological age controls on phonological discrimination, articulation rate, and nonword repetition' and were significantly worse than even the reading matched controls on the repetition of longer words. It was concluded that 11-year-old dyslexics show 'residual problems on phonological processing, especially for tasks involving unfamiliar stimuli, but that by their mid-teens dyslexic children have overcome these problems'. The dyslexics of both ages continued to display a lack of fluent articulation that was attributed to the slight deficit found on memory span. These results were accounted for by 'slow skill automatisation' with deficits diminishing as the dyslexic grew older. This showed that dyslexics displayed initial serious deficits but their overall learning processes were basically normal when investigated on a longitudinal basis.

Three studies on the mathematical abilities of dyslexics refer to weak memory skills (see 1.8.3 for further details on these studies). The first by Steeves (1983) demonstrated that the dyslexic children had 'inferior memory skills to both mathematically gifted and average non-dyslexic children' and that despite this, the gifted dyslexics were able to compensate by relying more on logical reasoning to solve problems and less on rote memory for retrieval of facts. Memory was the essential factor in the computational efficiency of the gifted dyslexics. The second study, by Pritchard et al. (1989), recognised the need for memorisation of multiplication number facts where regularity and pattern within the number system were not evident. Such memorisation by the dyslexics 'could not have been easy' in comparison to the better memory for associations in the case of the controls. Thirdly, Miles et al. (2001) sought to explain the reason why specific mathematical questions on the FMT (Friendly Maths Test), such as 'borrowing', proved to be extra difficult for the dyslexics. Judges' comments clarified the position that 'memory problems seriously impede the progress of dyslexics in mathematics' and that the problems of immediate memory result from dyslexics' 'slowness in processing speech sounds'.

A number of studies have found that children with mathematical and/or reading disabilities display: weak memory capacity on recall of digits (Webster, 1979; Hitch and McAuley, 1991; Koontz and Berch, 1996; Geary et al., 2000) and short-term memory tasks (Siegel and Linder, 1984), working memory deficiencies (Siegel and Ryan, 1989), difficulties in the 'representation or retrieval of arithmetic facts from semantic memory' (Geary, 1993), deficits in spatial working memory and aspects of executive processing (McLean and Hitch, 1999) and short-term memory deficits in part caused by lack of spontaneous verbal rehearsal (Torgesen and Goldman,1977).

1.5.4 Components of Working Memory

Baddeley has conducted the most influential research in this field stemming from a model of working memory first proposed by Baddeley and Hitch (1974).

Baddeley and Hitch (1974) identified three components of working memory: the central executive component, supplemented by two 'slave systems'– the phonological loop and the visuo-spatial sketchpad.

The central executive is the coordinator of the slave systems and provides overall attentional control (Baddeley et al., 2001) and is a very powerful system (Baddeley, 1996). It is able to perform switching retrieval strategies, such as utilising multiplication number facts in order to solve division questions and switching on carrying operations (Fűrst and Hitch, 2000). The central executive is able to attend selectively to a variety of inputs, such as attending to 'selected parts of a problem at different times' and 'activating and manipulating information in long-term memory' (McLean and Hitch, 1999). Additionally the central executive 'may play a number of critical roles in the high-level cognitive processes involved for skilled speakers in planning speech output' and 'it may contribute to the construction of semantic content of utterances' (Gathercole and Baddeley, 1993).

Conway and Engle (1994) presented their theory that the central executive is a general attentional system. This system is capable of inhibiting superfluous information that is irrelevant or 'off the goal path' so that it does not enter into an active state whilst at the same time activating and maintaining information that is relevant to the task. Baddeley (1996) added that a possible variable alongside inhibitory capacity was individual difference in excitatory processes.

The articulatory loop comprises two subsystems: a subvocal rehearsal process that is active and involves subvocal articulation and links with the speech production system, and a passive phonologically based store. This store, whilst it can decay (within about two seconds), can be maintained by subvocal rehearsal. Baddeley and Hitch (2000) refer to the loop as the phonological loop. Subvocal articulatory rehearsal is able to refresh visually presented nameable material in the phonological store by the use of articulation. The articulatory process is affected by the word length effect whereby 'the immediate memory span for words is a direct function of the length of the constituent items'. It is assumed that longer words take longer to articulate, thereby enabling forgetting to occur through interference or trace decay (Baddeley et al., 2002). The use of articulatory suppression, such as saying the word 'the' whilst performing a memory task, prevents conversion of a visual stimulus into a verbal form that can be registered in the phonological store. Access to this store is automatic with auditory presentation (Baddeley et al., 1975). Additionally the phonological loop has been found to have evolved in order to aid in the learning of new words in one's own language or other languages (Gathercole and Baddeley, 1990; Baddeley et al., 1998; Baddeley, 1999).

Like the articulatory loop, the visuo-spatial component has two subsystems: a system that retains visual material like shape and colour and another that retains movements through space (Logie et al., 1994).

Two-way links are proposed between the phonological loop, the visuo-spatial subsystems and long-term memory (Baddeley et al., 2001).

A recent development in the model of working memory is that of the episodic buffer proposed by Baddeley (2000b). It is assumed that the episodic buffer is accessible to conscious awareness, is involved in prose recall and can integrate information from the slave systems and long-term memory through the use of a multimodal code. It is dependent on the central executive but it differs in that its main purpose is as a storage device. 'It has limited capacity but is able to package information more efficiently through chunking into coherent episodes' (Baddeley et al., 2001). The episodic buffer helps to answer the problem of 'how information from different sources is combined to create the perception of a single coherent episode' (Baddeley and Hitch, 2000).

Material in our short-term memory is processed mostly in terms of speech sounds whereas long-term memory relies upon meaning (Baddeley, 1999). Hulme et al. (1991) showed that long-term memory makes a contribution to short-term memory span. The span is equal to a constant time interval of around 2 seconds – where the articulation rate depends on factors such as familiarity, word frequency and accessibility – which in turn dictates the 'magnitude of the long-term memory contribution to the span'. In another study Hitch et al. (2001) concluded that 'working memory span is constrained by rapid loss of active codes and is not simply a measure of capacity for resource sharing'. Thus the 'temporal dynamics of the task' are central to our ability to remember (Towse et al., 1998).

1.5.5 Memory and Arithmetic

Hitch (1978) alluded to a form of memory storage (in short-term working memory) required for mental addition when it was performed in stages, such as for addition of 437 and 52. Four types of problems were used: no carrying, carrying in the tens, carrying in the hundreds and carrying in both tens and hundreds. Each addition sum consisted of a three-digit number followed by a two-digit number to be added, to make a three-digit result. The results showed that adding was performed in stages and that forgetting was likely to increase with the number of calculation stages that occurred between the presentation of the problem and the subsequent use of the stored information. Interim information held in storage underwent rapid forgetting if it was not utilised immediately, as shown in errors produced on 'carried' tens and hundreds. The role of long-term memory was to provide '... the overall information processing strategy and the "number facts" for individual additions'. Hitch (1980) proposed that arithmetical calculation, as with reading, utilized storage within the articulatory loop and that the central executive had access to long-term memory (LTM) by 'activating sets of learned procedures'.

Likewise, Wolters et al. (1990) proposed that retrieval of number facts from a declarative knowledge base (in long-term memory) is achievable when arithmetic procedures such as adding, multiplying or dividing of large numbers are broken down into manageable subproblems. Storage, of both the original problem and the outcome of the subproblems, is required temporarily. Success at this task is dependent on: processing capacity, where subproblems can only be managed one at a time, and storage capacity, where a larger memory load is needed to solve multistep problems.

Ashcraft et al. (1992) drew a distinction between automatic retrieval of number facts with consequent low demands on working memory, and effortful processing, such as carrying and borrowing, requiring an 'attention-consuming, working memory system'.

In a later paper by Ashcraft (1995) the central executive was presumed to retrieve and manipulate numbers and facts, apply procedures, carry and borrow, hold onto intermediate values and contain 'keeping track mechanisms'. Interference with this would result in drainage of resources. The articulatory loop specialised in incremental counting and genuine counting with the possibility of holding intermediate values. It was speculated that the visuo-spatial sketchpad was involved in processing the visual characteristics of the problem and registering positional information although little research had been conducted in this area. Heathcote (1994) reported further evidence in support of the view that the visuo-spatial sketchpad functions as a 'mental blackboard upon which material may be visuo-spatially represented whilst various operations are performed on it'. Additionally Logie et al. (1994) proposed that the central executive was involved in performing calculations and 'producing approximately correct answers' whilst subvocal rehearsal enabled the maintenance of accuracy in mental addition.

Healy and Nairne (1985) produced a model of the counting process that featured the role of 'phonologically coded short-term memory representations of the numbers' in keeping track of location in the counting sequence. The sound of a number, such as in repeated digits (e.g. 77, 88) and decade numbers (e.g. 60, 50) influenced the likelihood of it being omitted in a counting sequence. The current contents of short-term memory needed to be checked in order to 'determine whether the number just generated has already been emitted'. Similarly Conrad (1964) showed that items were confused in a memory list when they sounded alike, reinforcing the influence of phonological factors whereby retrieval is affected by speech like attributes.

As a challenge to Baddeley and Hitch's (1974) model Butterworth et al. (1996) produced evidence of a neurological patient that displayed preserved calculation skills despite having an impaired auditory short-term memory. The patient (MRF) correctly answered 7 out of 12 of each multidigit addition questions (e.g. 128 + 149) and subtraction problems with carrying and borrowing (e.g. 119 – 35) within a 10-second time limit per problem. The questions were presented auditorily. MRF was a 52-year-old pharmacist whose calculation skills may have been unaffected by the brain damage and whose mathematical potential was unknown, for example we do not know how well MRF knew his number facts and could access these from long-term memory or if he had divided the problems up into stages. Butterworth et al. question the role that short-term memory (measured by span) plays in arithmetical calculation.

> The findings reported here conflict with the very clear intuition that we hold number words in our head when carrying out mental arithmetic ... However, it is possible that hearing the number words in our heads is epiphenomenal, and that the real work is being done elsewhere. (Butterworth et al., 1996)

The articulatory loop was therefore shown to be impaired yet calculation skills remained. It is possible, therefore that another or other components in working memory were able to compensate – such as the episodic buffer (Baddeley, 2000b).

Adams and Hitch (1997) showed that performance on mental addition was found to improve when the problem was presented visually so that it was permanently available, thereby reducing the load on working memory.

Issues of memory that might influence performance on mathematical operations can be summarised as: memory recall affected by rate of articulation, memory span, the effects of memory on computational efficiency, memorization of multiplication number facts, working memory including the central executive, the phonological/articulatory loop, the visuo-spatial sketchpad and the episodic buffer, memory storage and retrieval of mathematical number facts, the effect on memory of mathematical manipulation and memory representation of numbers in long term memory.

1.6 Delays and Deficits

This section includes research findings on two differing approaches towards dyslexia – that of a delay or maturational lag in dyslexia and secondly that of deficits accounting for dyslexia.

1.6.1 Introduction – Delay

The delay hypothesis implies that dyslexic children pass through the same stages of learning as non-dyslexic children, but at a slower pace. Thus studies seeking to investigate a delay or deficit include participants who are matched with the dyslexics on age and reading or spelling age. Evidence of just a delay is found where the dyslexics perform worse than the age matched controls but better than the reading or spelling matched controls. A deficit is indicated where the dyslexics perform worse than both the age matched and reading or spelling matched controls.

1.6.2 Studies Showing a Delay

The following studies have been chosen because they show evidence of a delay in the performance of dyslexics.

Critchley (1970) observed that minor neurological signs found in young dyslexics were not as evident in the older dyslexic. These signs were cited as 'epiphenomena – significant when they occur, but not essential in any consideration as to pathogenesis or aetiology'. Critchley wrote of 'maturational lag' as synonymous with being a 'late bloomer', whereby maturational lag did not indicate that there was a deficiency, loss or any structural defect and indeed maturation could speed up at various times. Two difficulties occur in verifying a delay: lack of longitudinal evidence and being precise about which specific skills are delayed due to their interrelatedness.

Done and Miles (1988) made a calculation on the basis of their data which suggested that the age of word acquisition in dyslexics was 10.8 months later than a non-dyslexic peer, based on slower response latencies for picture naming (see 1.4.1 for details).

Nicolson and Fawcett (1994a) compared the performance of 11- and 15-year-old dyslexics to three groups of non-dyslexic children matched on age, IQ and reading age on a range of tasks designed to investigate speed of information processing. One of the tasks was selective choice reaction whereby the subject pressed a button only on hearing a low tone. The dyslexics performed significantly slower and less accurately than the age-matched controls whereas their performance was at the same level as the reading-age matched controls. A similar result was found on speed of conducting a lexical decision task whereby the subject had to choose if a spoken word was a real or nonsense word. However, when the results were displayed using 'by-item' analysis, the dyslexic children showed a deficit in lexical decision speed – whereby they performed more slowly than even the reading-age controls. The likely reason for this deficit was proposed as the time taken to classify the stimulus or the longer time for the central executive to make a decision. Therefore as 'task complexity increased, the deficits shown by the dyslexic children became more marked'.

The results found by Nicolson et al. (1991) also indicated both a deficit and a delay in the performance of the dyslexics (see 1.5.3 for more details). A delay was shown on tests of phonological discrimination, nonword repetition and articulation rate. Phonological processing difficulties found for the 11-year-old dyslexics diminished with age by the mid-teens and the delay was attributed to slower automatic skill development.

Fleischner et al. (1982) found that grade 3 children who were learning disabled (LD) performed notably less well than older LD children on basic fact computation. A possible reason for this was given as 'these children may simply have been delayed in arriving at the stage where computational accuracy might be expected of them. This might reflect a prolonged period of arithmetic readiness instruction in the first years of schooling, or might reflect the children's inability to grasp number concepts at the ages when nondisabled children did' (p. 55).

Snowling et al. (1986) studied the processing of speech in dyslexics and found evidence of a delay in the repetition of low frequency words but signs of a deficit, where the dyslexics performed worse than the CA (age-matched) and RA (reading-ability-matched) controls, on the repetition of nonwords.

Brown and Loosemore (1994) devised a computational model within a connectionist framework to represent reading and spelling performance. A connectionist network was proposed whereby each unit has connections to other units in the network, in most cases. Each unit has an activation level that can be communicated to another unit, which is influenced by the 'strength' of that connection. A 'threshold' value must be exceeded for a unit to become activated, as when a number of other units are contributing at the same time. 'The amount of influence that one unit has on another (if they are connected) depends on both the size of its own activation level, and the strength of the connection between the two units'. Learning takes place in the course of experience whereby modification of connection strengths occurs. The units in the network are either input, output or hidden – the hidden units are used to 'represent regularities in the corpus of patterns that it sees'.

They showed that the dyslexic version of the model exhibited a delay in performance with respect to the reading of regular and irregular words and this was attributed to the dyslexics having fewer resources causing them to learn more slowly. However, a deficit was shown in nonword processing.

When adapted to the task of spelling, the model recognised that regular words had many 'friends', which were words similar in orthography and phonology, and that irregular words had only 'enemies' such as words with similar phonology but different orthography. It was demonstrated that dyslexics could be represented in the model by allocating fewer hidden units, and thereby resources, to them. The results for regularity showed that the dyslexic versions of the model (mildly or severely dyslexic) learned more slowly and did not achieve a comparable level of accuracy as the non-dyslexic version. An assessment of nonword performance produced marked inaccuracies in the dyslexic versions. In conclusion the model was successful in showing how the allocation of fewer hidden units accurately represented the known performance of dyslexics. Thus the influencing factor was the smaller number of computational resources that the dyslexic was able to bring to the task. 'We have argued that much of the pattern of difficulty experienced by dyslexics in spelling can be explained in terms of the dyslexic children allocating fewer processing resources to the learning process' (Brown and Loosemore, 1994, p. 216).

1.6.3 Introduction – Deficit

The delay hypothesis, whilst having been demonstrated, does not hold up to the many accounts of impaired dyslexic performance in comparison to non-dyslexics who are many years younger than themselves. A deficit is pronounced, fundamental and long lasting. An example of this is given in the following research.

An example of a deficit is shown by Trites and Fiedorowicz (1976) who undertook a longitudinal study of 27 children with an initial mean age of 11:6 years and mean age of 14:1 years at the time of the second testing. They had been diagnosed with a specific reading disability. The results showed that the deficit persisted with age and tended to 'grow larger relative to their age and grade placement'. The findings led the researchers to discount the hypothesis of maturational lag since this would not explain the persistence of the deficit into adulthood.

1.6.4 Phonological Deficit

The phonological deficit hypothesis is only briefly detailed. See the section on phonology in 1.4 on 'Articulation'.

Problems of language were recognised as being responsible for reading deficits (Vellutino, 1979). This general hypothesis has been cultivated over time (Liberman et al, 1974; Bradley and Bryant, 1978, 1983; Miles, 1983, 1993; Snowling et al., 1986; Catts, 1989) to produce currently what is known as the phonological deficit hypothesis. The nature and depth of the deficit depends on the phonological processes that are impaired. The early impairment of phonological skills in young dyslexic children prevents them from acquiring decoding and blending skills required for normal reading progress. Nevertheless this deficit does not account for all difficulties experienced by dyslexics.

However, 'there is a growing body of evidence that children with dyslexia have problems not just in reading but in a range of skills including several unrelated to reading' (Nicolson and Fawcett, 1994b).

1.6.5 Which Deficits?

Bearing this in mind, Nicolson and Fawcett (1994b) designed a research programme to examine dyslexic performance on a wide range of 'primitive' cognitive and motor skills. They compared dyslexics and controls aged 8, 12 and 16 years of age matched on age and IQ. Twenty-two comprehensive tests of phonological skill, working memory, information processing speed and motor skill were presented, such as: threading beads, balancing on one or two feet on a low beam – sometimes blindfold, dual balance (balancing whilst performing a secondary task such as counting or performing a choice reaction task), picture, colour, letter and digit naming, simple reaction time, choice reaction time, memory span, articulation time, segmentation, rhyme, phonological discrimination and nonword repetition.

The results showed that overall the dyslexics were significantly weaker than the age-matched controls on 20 tests (all except the simple reaction time and memory span, but there was a trend towards memory weakness). The dyslexics performed particularly poorly in relation to the age-matched controls on the tests of phonological skill, and on the phoneme segmentation task the older dyslexics were weaker than the reading-age controls. The young dyslexics showed severe impairments in relation to their age-matched controls on memory, articulation and several measures of processing speed (picture naming and word flash). The most pronounced results were shown on the motor skills tasks – bead threading and balance (blindfold and dual balance) whereby the dyslexics were poorer than both the age-matched and reading-matched controls. 'Indeed, despite the advantage of eight years experience, the oldest children with dyslexia had not advanced significantly beyond the performance of the very youngest controls on these three motor tasks'. Thus in general the dyslexic deficit was seen in all the primitive tasks tested. The young dyslexics displayed a 'range of profound deficits' that was most noteworthy. Progress was made with age, by the dyslexics, in speed of processing and memory but not in phonological skill and especially balance. Selective choice reaction time was challenging for the dyslexics in all conditions – with and without linguistic stimuli and for both visual and verbal stimuli. Their performance was similar to the reading-matched controls. On motor skills the young dyslexics showed 'severe initial deficits'. Therefore overall those tasks that showed up severe deficits, where the dyslexics performed more poorly than their reading-matched controls, were: 'segmentation, rhyme, word flash, picture naming, bead threading, balance on one foot with blindfold and dual balance'.

Nicolson and Fawcett (1994b) proposed the automatisation deficit as the most likely to account for the range of deficits found. However, they recognised that this deficit did not explain, for example, why the young dyslexics displayed the most marked difficulties that then diminished with age and therefore practice. In a concluding remark the authors looked to the future by writing: 'A causal theory should surely attempt to link the range of deficits to underlying neural mechanisms'.

Nicolson and Fawcett (1995) published a paper entitled 'Dyslexia is More than a Phonological Disability' in which they raised the issue of typical dyslexic weaknesses on aspects not related to phonological processing, such as being: forgetful, distractible, clumsy – displaying problems with motor skills and showing poor handwriting skills.

1.6.6 Slow to Pick up the Familiar and Automatisation

Denckla and Rudel (1976) used the word 'automatised' to refer to rapid naming difficulties that lacked automatisation in dyslexic children. This weakness was pronounced enough to distinguish dyslexics from normal controls as well as non-dyslexics who were otherwise learning disabled. The order of naming speed from quickest to slowest for all overall was: numbers and letters equally, colours and lastly object names, and the older subjects named more quickly. The researchers recognised the need to identify the source of the problem in automatisation.

Done and Miles (1978) detailed evidence that dyslexics are weak at paired associate learning (see 1.3.2 for more details) and their work showed that dyslexics require more 'exposures' before a name is remembered. Miles et al. (2001) likened this difficulty to the automaticity framework developed by Nicolson and Fawcett (1990) by writing: 'It is presumably part of the same limitation that dyslexics require more exposures to the same stimulus than non-dyslexics before their responses become automatic'.

Reading disabled children were shown to be at risk of becoming 'numerically incompetent adults' because of their difficulty in automatising basic number facts. Generous time limits masked this weakness in younger school-aged children (Ackerman et al., 1986). The understanding of the term poor reading should be treated with caution since there are a number of reasons why people should be poor at reading. The use of the term dyslexia implies greater specificity (Miles and Miles, 1999).

Where a process such as arithmetic is performed automatically there is less reliance on working memory whereas if conscious calculation is required, then substantial resources from working memory will be utilised. The most important factor for achieving automaticity is having a stored item readily available for retrieval in memory. However, evidence from an experiment on multiplication facts showed that 'multiplication is performed at a level substantially less than fully automatic' therefore implicating the involvement of working memory (Ashcraft et al., 1992). It was proposed in conclusion that simple arithmetic processing is not performed autonomously and therefore initial thoughts, whereby progression through childhood should be reflected in a change from conscious processing to an automatic response when performing the basic mathematical facts, needed to be re-examined.

Nicolson and Fawcett (1990) investigated the 'dyslexic automatisation deficit (DAD). This theory predicts that dyslexic children should have deficits on all cognitive and motor skills that require automatisation but that these are masked by 'conscious compensation' (CC) produced due to incomplete automatisation. Dyslexics would therefore have to work harder than normal children, resulting in difficulties on 'resource-intensive tasks', especially where stress was involved. Such conscious compensation could only be maintained for short periods because of the effort required. Dual tasks were designed so as to highlight an automatisation deficit whereby conscious monitoring would be made more difficult, for example balancing on a beam whilst counting backwards. Nearly all the dyslexic subjects (aged 13 years) found the dual tasks challenging whereas not one of the controls (also aged 13 years) were affected.

Along the same theme, Nicolson and Fawcett (2000b) investigated long-term learning in dyslexic children. In this paper they referred to their earlier work on the DAD hypothesis, stating that 'it is now generally accepted that automatisation must be more fully operationalised before it may be used as an explanatory construct'. The aim was to investigate the stages within the learning process that might be difficult for dyslexic participants. Dyslexic participants of mean age 14:9 years were compared to non-dyslexics matched on age and IQ on tasks monitoring skill acquisition, such as using computer keys to navigate a version of 'Pacman' (a readily available computer game) around a course. Many opportunities were provided for this skill to be optimised. Two weeks after the participants had become automatic, the commands from the navigating keys were changed so that the task had to be relearned and much practice was given until there was no further improvement in completion time. The final phase of the experiment took place after one year and the participants were measured for long-term learning of previous skills as well as new learning tasks on the Pacman game and performance on a dual task. The results showed that the dyslexics produced much worse initial performance with between 40–80% greater completion times and about 30% more errors than the controls and the dyslexics were not as able to eliminate their errors by the end of a phase. By the final phase the quality of the dyslexic performance was slower and less accurate despite taking more trials to reach the required level. The dyslexic performance was marked by the continued presence of errors despite extensive training.

A second study, inspired by the earlier findings (Nicolson and Fawcett, 1994a) on simple and choice reaction times, was designed whereby dyslexics of mean age 14:8 years were compared to non-dyslexic children matched for age and IQ. The participants were initially tested on two simple reaction tasks (SRT) – to press a button with their preferred hand immediately on hearing a tone and secondly to press a foot switch as soon as possible on seeing a flash. One hundred trials were conducted to create baseline results. Following this stage, both stimuli were presented in order to create two choice reaction conditions (CRT): one was foot-flash, hand-tone and the other was hand-flash, foot-tone, and 100 trials were administered. The results showed that there were no differences in response latency, for either the flash or the tone conditions, between the dyslexics and controls on SRT. On CRT initially the dyslexics made slightly more errors than the controls but this rose to about twice the number of errors, compared to the controls, by the final session. The final speed of response by the dyslexics on CRT was much slower (on both hand and foot responses) than their SRT speed whereas the controls showed no difference between these times. This showed that dyslexics had difficulty in blending the two skills together despite much practice. In summary it was shown that dyslexics are as able to acquire new skills and have normal 'strength of automatisation' – defined as resistance to unlearning and forgetting with an ability to 'operate independently of other skills'. However, it was clear that dyslexics have 'greater difficulty in blending existing skills into a new skill, and their performance after extensive practice (such that skill was no longer improving noticeably) was slower and more error-prone'

(p. 386). In other words, they were simply less skilled and their quality of automatised performance was lower.

To describe dyslexic difficulties under the broad banner of an automatisation deficit 'explained neither the cause nor the specific pattern of difficulties' (Nicolson and Fawcett, 1999) and therefore it became apparent that attention should be focused upon the brain mechanism responsible for the observed difficulties.

Nicolson and Fawcett (2000b) argued that these results favour a cerebellar deficit hypothesis where two functions of the cerebellum are to execute acquired skills (especially involving motor skills) and to aid in the acquisition of new skills. This hypothesis 'provides a plausible underpinning to established findings of phonological deficits, visual deficits, speed of processing deficits, and automatisation deficits' (p.386).

1.6.7 Cerebellar Deficit

It became evident that the focus on the cause of dyslexia should be directed at underlying physiological processes that would account for the non-linguistic and language difficulties.

Denckla (1985) wrote of motor coordination difficulties in dyslexic children as attributable to 'cerebellar' dysfunction. It was proposed that there is a maturational lag in the system responsible for 'timed, sequential, detailed movements' of dyslexics. At the age of 7 and 8 years dyslexic children showed slowness on toe tapping and sequential movements of finger and thumb touching with success reached after much rehearsal and effort.

As a follow-up study, Wolff et al. (1990) compared the performance of adolescent (aged 13 to 18 years) and adult dyslexics (aged 18 to 32 years) with controls matched on sex and age, on tasks of rhythmical finger tapping. The main findings were that both age groups of dyslexics showed significant lack of timing precision on bimanual coordination compared to the age-matched controls. It was proposed that timing required in speech and language skills would be affected by the motor deficit displayed by dyslexics.

It was proposed that a mild dysfunction of the cerebellum was in part responsible for the range of symptoms shown in dyslexia (Nicolson et al., 1995). Like the work of Wolff et al. (1990) Nicolson et al. (1995) studied timing skills in dyslexics. Dyslexic children (aged 9, 14 and 18 years) were compared to non-dyslexic children matched on age and IQ on a time estimation task. A standard pure tone was played for 1200 ms that was then followed by a comparison tone of shorter or longer duration providing a choice decision as to the relative length of the tones. An equivalent procedure was then presented for an estimation of loudness. The results showed that for all, sensitivity to both loudness and time improves with age. The dyslexic groups showed impairment on the time estimation task but not the loudness estimation task, even when the 14- and 18-year-old dyslexics were compared to reading-matched controls. Overall the research programme devised by Nicolson and Fawcett:

> provides strong converging evidence for the hypothesis of cerebellar dysfunction in that the strongest effects are for automatic balance (directly linked to the cerebellum), temporal estimation (linked to the cerebellum via neuropsychological studies) and segmentation (an aspect of linguistic dexterity, in the acquisition of which the cerebellum is claimed to play an important role). (p. 46)

Vellutino (1979) and Miles (1993) provide other examples of a broader temporal weakness in dyslexics such as: telling the time, naming the months of the year, seasons or days of the week in order. Experienced practitioners will have noted the lack of awareness that dyslexic children have with time of day, timing of events in a day or length of time that tasks take.

Two classic cerebellar signs were described as: incoordination (where in severe cases the walk resembles that of someone who was drunk) affecting balance and the execution of complex movements, swaying, and secondly dystonia (loss of muscle tone) causing tremor, floppiness and difficulty in braking movement (Nicolson and Fawcett, 2000a).

In tests designed to assess muscle tone and coordination, Fawcett et al. (1996) compared the performance of 10-, 14- and 18-year-old dyslexics with that of controls matched on age and IQ. The design enabled the 14 and 18-year-old dyslexics to be matched on reading age with the 10- and 14-year-old controls respectively and the 18-year-old dyslexics could be compared with the 10-year-old controls who were roughly half their age. The test included maintenance or posture (balance time and postural stability), hypotonia or reduced muscle tone (static tremor, arm displacement, weight time, hand declination, arm shake, muscle tone, braking distance) and complex movements (past pointing, finger-to-finger pointing, adiadochokinesis, toe tap speed and finger and thumb). The results showed that the dyslexics performed significantly worse than the controls on all 14 tasks. When compared to the reading-age controls (controls 10 years and dyslexics 14 years) the dyslexic performance was significantly worse on 11 out of the 14 tasks (all except tremor, muscle tone and finger-to-finger pointing). The 10-year-old dyslexics displayed 'markedly reduced muscle tone'. On the test of adiadochokinesis many of the dyslexics could not keep up with the pace and lost their rhythm. Strikingly the 18-year-old dyslexics were consistently worse than the 10-year-old controls on many tasks. In the ensuing discussion, the findings point to the role of the cerebellum in articulation.

> If articulation is less fluent than normal, then it takes up more conscious resources, leaving fewer resources to process the ensuing sensory feedback. In particular, the processing of the auditory, phonemic structure of the words spoken may be less complete. There may, therefore, not be a natural sensitivity to onset, rime, and the phonemic structure of language – in short, one would expect early deficits in phonological awareness. (Fawcett et al., 1996, p. 279)

For a detailed account of the 'specific role of the cerebellum in motor learning and cognition' the reader is referred to the work of Thach (1996). One particular find of interest is that the cerebellum was activated during internal speech.

In a later study, brain activation was monitored in dyslexic adults whilst performing finger movements (Nicolson et al., 1999). Six dyslexic males matched on age (mean age 21 years) and IQ with six male controls performed a prelearned sequence of finger movements whilst brain activation was measured by positron emission tomography. The dyslexics made more errors despite overlearning of the sequence of movements. A new sequence of movements was introduced and on this and the prelearned sequence it was found that cerebellar activation was less extensive for the dyslexics than the controls when compared to the rest position. The overall finding 'suggests that the cerebellum does not contribute towards the acquisition of motor sequences in the same way for dyslexic as for non-dyslexic people'. The motor learning task had been carried out with eyes closed, and this factor showed that the visual magnocellular system was not contributing to the brain activation differences found in the dyslexics.

The reason for spelling difficulties often being more severe than reading (Thomson, 1990) can be explained by a 'twin deficit route' (Nicolson and Fawcett, 1999) whereby handwriting, affected by reduced motor skill, and spelling influenced by weak automatic knowledge of spelling patterns and orthographic accuracy, together present a greater dual task challenge. It may be that the cerebellum is implicated in the dyslexic weakness at recognising articulatory movements as represented in cross-sectional diagrams of faces making particular sounds (Griffiths and Frith, 2002). Indeed Thach (1996) alluded to the role of the cerebellum in coupling gesture of the face (and hands) with speech. Such a weakness would render the task of spelling harder to produce, for the strategy of 'sounding out' would be less efficient.

Fawcett and Nicolson (2001) conclude that the CDH (cerbellar deficit hypothesis) is a 'biological-level hypothesis that is well described at the cognitive level as an automatization deficit hypothesis. The two hypotheses between them have provided a true causal explanation of the varied findings in dyslexia research' (p. 102). But this may not be the end of the story.

The two main issues in this section, namely whether dyslexia can be described as a maturational lag or as a deficit have found support in the research reported here. This section "sets the scene" for the research findings in this thesis.

1.7 Responding at Speed

The participants in this research were required to respond to mathematical tasks under timed conditions. Issues of responding at speed are explored.

1.7.1 Magnocellular Deficit

Livingstone et al. (1991) provided 'physiological and anatomical evidence for a magnocellular deficit' in dyslexia. It is not proposed to embark on either anatomical or physiological details of the findings suffice to report that a comparison of five dyslexic and non-dyslexic brains revealed abnormalities in the magnocellular layers (more disorganisation and smaller than normal) but not the parvocellular layers of the five dyslexic brains. The magnocells had smaller cell bodies with consequential thinner axons leading to 'slower conduction velocities'. Magnocells are responsible for the processing of fast, low-contrast visual information whereas the parvocells process slow, high-contrast information. In an experiment designed to study response to fast presentation of visual stimuli, dyslexics responded slower than normal. One possible role of the magnocellular system in reading was proposed as inhibiting the image of fixations from one saccade to another. This finding is similar to that provided by Wolf and O'Brien (2001) in their report on the need for inhibition during the inter-stimulus interval (see later in section 1.7). Livingstone et al. (1991) raised the possibility of other similar systems with fast/slow subdivisions being implicated, whereby the fast or rapid subdivision may be slower in dyslexics. Stein and Talcott (1999) speculated that immunological attack by antibodies effects magnocellar development and that this can occur in any 'of the magnocellular neurons throughout the whole brain'. Indeed, Stein (2001) states that: 'The cerebellum is the head ganglion of the magnocellular systems; it contributes to binocular fixation and to inner speech for sounding out words, and it is clearly defective in dyslexics'.

1.7.2 Decision Making

Pritchard et al. (1989) asked dyslexics to indicate if they had to 'work out' their answers to multiplication sums in order to ascertain if a 'number fact' was known. Thus the dyslexics had to judge if they had responded instantly without calculation.

Included in the instructions were the following directions: 'I think sometimes people automatically start to work things out without even knowing that they are doing it; and if you suddenly find that you are working the table out, stop and just say "working out"' (p. 18). This required conscious awareness on the part of the participants in determining whether they had begun to calculate. Weiskrantz (1985) raised the issue of conscious awareness. He suggested that this can take two forms: firstly reflective thought on 'stored categorical knowledge and associations' including the use of imagination, and secondly an awareness of the present. He proposed that some sort of monitoring system links these two. He stated that in order to be aware of our behaviour we require 'a link between our earlier concern with reflection and our present one with awareness. It would be a waste of cerebral processing to have to continue to dwell on redundant information or automatic control' (p. 17).

The age at which decisions are made has an effect on the speed and efficiency of the outcome. The decision as to whether addition problems were true or false involved increasingly sophisticated internal verification processes that had developed substantially in children from grade 3 to grade 6 (Ashcraft and Fierman, 1982).

When dyslexics had to make decisions based on choice reaction, Nicolson and Fawcett (1994a) found that their difficulties were pronounced. The dyslexics may have taken longer to classify the stimuli because they were presented in a dual-task framework or that the decision-making process took longer.

1.7.3 Issues of Speed

Miles and Wheeler (1977) found evidence that appeared to support the claim that dyslexics are limited in their ability to handle complex stimulus material in a short length of time, in an experiment using tachistoscopically presented digits. The subjects were aged 14 to 21 years.

In a later paper, Ellis and Miles (1977) sought to study younger dyslexics (average age 12 years) on a similar task. A number of digits (from four to seven) were presented tachistoscopically, at an exposure time of 400 to 1,600 ms, to dyslexics and spelling-matched controls. The dyslexics recalled less numbers of digits in each condition compared to the younger controls, thereby confirming that an explanation of the dyslexic difficulties in terms of a 'maturational lag' was not feasible. It was concluded that dyslexia 'involves some kind of special limitation in the ability to process information'. Additionally Bull and Johnston (1997) found evidence of slow speed in number identification, number matching, perceptual-motor performance and execution of arithmetical procedures in 7-year-old children with arithmetical difficulties, although it is not clear from this study if any dyslexics were included.

Ellis and Miles (1981) recognised that dyslexics had more marked deficits under timed conditions and Denkla and Rudel (1976) found that dyslexics lacked speed of access to words that were spoken in an experiment conducted on children with arithmetical difficulties.

In a later study, language-impaired children were found to have a basic temporal processing impairment, affecting normal language and reading development, speech perception and speech production (Tallal et al., 1985; Tallal et al., 1993). This was thought to be due to a difficulty in processing 'sensory information entering the nervous system in rapid succession (within milliseconds)' especially when integrating converging information through the different senses, leading also to slower motor output. By definition, language impairment refers to a slower than expected rate of language development despite other areas of development being normal.

Wolf and O'Brien (2001) proposed a double-deficit hypothesis in dyslexia that integrates phonological and naming speed research. This research centres on reading with fluency as a key factor. This is affected, in part, by the inter-stimulus interval – the gap in time from a response to one stimulus and the response to the next stimulus. During this gap, the response to the previous stimulus needs inhibiting.

Nicolson and Fawcett (2000b), however, questioned the ability of a rapid processing deficit in explaining all of their findings on the Pacman task (see 1.6.6 for further details) whereby the prime difficulty for the dyslexics was the continued presence of errors despite extensive training, stating that 'the difficulty lies not with the speed of response but with making the correct responses'.

1.7.4 Inhibition

This section has been included because there are inhibition difficulties reported in both the field of mathematical research and literacy (e.g. Wolf and O'Brien, 2001) as well as that of memory and physiology and anatomy (e.g. Livingstone et al., 1991) in connection with learning difficulties.

In the field of mathematical research, Barrouillet et al. (1997) identified that the errors produced by adolescents with learning difficulties (LD) was due to inefficient inhibition of competitor products in multiplication tasks. The experiment included 24 seventh grade subjects (mean age of 13:9 years) who were attending special classes (the LD group). A previous experiment had been conducted without any distractors to form a baseline for comparison. Multiplication problems of the type 'a × b = ?' were projected onto a screen for 7 seconds each and the subjects wrote down their responses in a booklet that presented a range of possible answers to the problem in a multiple choice format – a correct response and three distractors. The distractors had been selected so as to include numbers close to the correct answer (e.g. for 4 × 6: 22, 23 and 26), or numbers from the Pythagorean table that were closest to the correct product but did not form part of the table for either of the multiplicand or multiplier (e.g. for 4 × 6: 21, 25, 27) or a third condition where the three distractors were numbers forming part of the table for the multiplicand or multiplier (e.g. for 4 × 6: 3, 18, 28). The results showed that most errors occurred in the third condition – thus 'LD adolescents encounter problems that are specific to the inhibition of correct responses to operations in which the operands are associated with competitors'. This implies that the problem is one of information retrieval where the facts have been stored in memory and organised in such a way that competitors arise. It may have been possible, however, that the 7 seconds afforded to the subjects per question enabled them to use calculation to arrive at the answer. Nevertheless, Geary et al. (2000) also support the theory of poor inhibition of irrelevant associations by MD (mathematically disabled) and RD (reading disabled) children alike. Likewise Leong and Jerred (2001) and Koontz and Berch (1996) recognise the potential of an inefficient inhibitory theory.

Dehaene (1997) refers to young children being unable to inhibit a spontaneous but incorrect tendency when they respond impulsively to a question such as which row has the greater number of objects. Their response is often based on the length of the row rather than the actual number of objects, despite their competence in number processing.

In the field of memory, Conway and Engle (1994) stated that 'people with inefficient inhibitory mechanisms will allow information that is off the goal path to enter working memory'. They proposed that subjects with low-memory spans were not as adept at inhibiting activation of irrelevant and weaker information thereby enabling the information to come into an active state. Similarly, Baddeley (1996) explored the functions of the central executive (see 1.5 for more details) and suggested that the central executive has the capacity 'to attend selectively to one stimulus and inhibit the disrupting effect of others'. Any effect of inhibitory weakness in memory has yet to be explored in dyslexia.

Fawcett et al. (1996) conducted a muscle tone experiment on dyslexic children whereby the distance of elbow travel was measured in a sudden pencil release task. Both the experimenter and the subject pulled at opposite ends of a pencil and the experimenter released the pencil unexpectedly. The distance of elbow travel backwards, as a result, was taken to indicate braking distance before backward movement was arrested. The results showed that the greatest difference between the dyslexics and age/IQ matched controls was at the age of 10 years with a breaking distance of 3.89 inches compared to 1.44 inches for the controls. The difference was still present at the age of 14 years (3.33 inches and 1.23 inches respectively) but had decreased by the age of 18 years (1.56 inches to 1.04 inches respectively). Thus the dyslexic groups were unable to inhibit their responses as effectively as the controls, especially at a younger age.

When conducting experiments on dyslexics it is important to record behaviour, such as comments made, exclamations, bodily movements and pauses, shown beyond the scientific data being collected. Miles (1993) raised this issue when considering how to score the 'crikey' response on the Bangor Dyslexia Test. He observed that a bright 11-year-old dyslexic had instinctively replied '"Oh, crikey"' when asked to recite the months of the year. Such a comment indicated that the dyslexic considered the task a challenge, but nevertheless he was able to answer correctly albeit with a struggle. Such instances prompted Miles to emphasise that 'If one fails to score the "crikey" at all one is throwing away potentially useful data'. In this way, uninhibited responses can be recorded and comparisons made with those of non-dyslexics. An account of additional behaviour shown by dyslexics is given in 1.10.

Main findings on responding at speed, that are relevant to this research include: the magnocellular deficit, decision making, processing stimulus material at speed and the issue of inhibition.

Part 2: Dyslexia and Mathematics

1.8 Research on Dyslexia and Mathematics

1.8.1 Introduction

This section gives a review of mathematical research and knowledge on dyslexics, including a list of relevant published work on teaching mathematics to dyslexics.

An Internet search on PsycINFO dating back to 1887 shows 3468 entries for the keyword 'dyslexia' whereas only 37 of these entries are given for 'dyslexia and mathematics'. Of these 37 entries, 17 are listed from 1992 onwards. Thus this field of research has received little attention in comparison to the subject of dyslexia as a whole. One reason may be that it is more socially acceptable to have numerical difficulties than poor literacy skills (Gross-Tsur et al., 1996).

Morgan (1896) briefly alluded to the mathematical progress of his dyslexic patient, Percy: 'I next tried his ability to read figures, and found he could do so easily. He read off quickly the following: 785, 853, 017 ... He could not do the simple calculation $4 \times \frac{1}{2}$, but he multiplied 749 by 867 quickly and correctly'. This latter ability seems very surprising indeed in view of other findings in this thesis.

1.8.2 Being a Successful Mathematician

Benbow (1987) studied boys and girls in grades 1–3 and claimed that no gender differences were found on correctness for solving: number facts, multidigit addition, subtraction word problems and computation tasks. Differences were found between the strategies used by both sexes. Girls tended to model and count whereas the boys used more abstract strategies that 'reflected conceptual understanding'. Additionally those boys and girls who had used invented algorithms early were the most able to solve extension problems in grade 3 (Fennema et al., 1998). These studies along with that of Miles et al (1998) on gender ratio for dyslexia (4.5 males to 1 female) reinforced the decision to use only male participants in the present research.

A personal account of a talented mathematician who was also dyslexic is given by Jansons (1988). He obtained a PhD in mathematics and became a university lecturer in the subject. He attributed his success in part to being able to create original mathematical ideas through visualisation and a 'deep intuition'. 'From an early age I found that many things were easier to think about without language ... I soon found it reasonably easy to create images in my mind and to manipulate them'. Jansons' academic progress was accelerated by an understanding parent and by meeting educators who recognised his talent and provided a supportive environment. This is in direct contrast to the difficulties that he encountered with his education when younger.

Steeves (1983) warned of the dangers of not recognising the needs of gifted children and wrote:

> The highly intelligent dyslexic, already an under-achiever in the area of language, becomes doubly handicapped if his or her mathematical talent is not fostered or challenged. If mere computational efficiency is the only predictor of achievement in the professions which involve spatial ability, clear thinking, and logic, many potentially successful architects, surgeons, and creative mathematicians may be unnecessarily denied the full use of their talents.

T.R. Miles (in Miles and Miles, 1992) called into question the diagnostic value of the WISC (Wechsler Intelligence Scale for Children) (Wechsler, 1969) Arithmetic sub-test and the Basic Arithmetic item in the British Ability Scales (BAS) whilst recognising the established phenomenon of the ACID profile. This is an often-found dyslexic weakness at the Arithmetic, Coding, Information and Digit Span sub-tests of the WISC. The items in the Arithmetic sub-test of the WISC are read orally with only one repetition allowed. This may highlight memory problems. There are also time limits for every answer and therefore 'those who process information slowly may be at a disadvantage'. Knowledge of tables is required from item 10 onwards. This is 'something at which dyslexics are known to be weak' (Miles, 1983). Because of the layout of this sub-item the distinctive difficulties of the dyslexics may not be exposed in a 7- or 8-year-old dyslexic. Overall, for a dyslexic, this sub-test 'may represent a kind of compromise between his high reasoning ability and his typical dyslexic weaknesses'.

Thomson (1982) showed that dyslexics in each of three age groups, ranging from 8 to 16 years, performed particularly poorly on the Basic Arithmetic item in relation to certain other items such as Visualization of Cubes, Matrices and Similarities.

1.8.3 Studies of Dyslexic Performance on Mathematics

The studies have been presented in chronological order.

Frauenheim (1978) tested the academic achievement of 40 males who had been diagnosed as dyslexic in childhood. The results on reading, spelling and arithmetic tests showed that original learning problems had persisted into adulthood. 'All 40 subjects acknowledged that they still had difficulty with the multiplication tables and had never adequately or fully learned them ... A number of subjects had difficulty with problems requiring regrouping or borrowing in subtraction'.

In 1981 Joffe submitted a PhD entitled 'School Mathematics and Dyslexia: Aspects of the Interrelationship'. The Abstract states:

> This investigation sought to explore the nature and extent of school mathematical difficulties among the dyslexic population ... Studies 3 and 4 reveal that dyslexics' performance on a range of school mathematical topics gets relatively worse compared with that of Controls (age range 8–17 years), as they get older.

'Poor short-term memory, sequencing skills and verbal labelling strategies' were shown to account for the difficulties. Study 3 included an analysis of untimed performance on calculation using the four operations of addition, subtraction, multiplication and division, using the Basic Arithmetic Scale of the British Abilities Scales. Overall 60% of the dyslexics (aged from 8 years to 16 years 11 months) gained an arithmetic age that was lower than their chronological age whereas this figure was 19% for the controls. All subjects were of average intelligence or above.

In a subsequent paper by Joffe (1983), arithmetical errors made by the dyslexics were detailed: lack of appreciation for place value and grouping by ten as part of our conventional number system, regrouping errors in addition and subtraction which accounted for up to 40% more errors made by the dyslexics than same-aged controls and difficulty in recalling number facts. Joffe offered her own definition of dyslexia in the light of her own research:

> Dyslexia is primarily a neurological dysfunction which manifests itself mainly as an inability to use verbal labelling and generalisation strategies appropriately to facilitate the fluent acquisition and memory of symbolically mediated material, such as written language and school mathematics. It also influences other aspects of general functioning, the range and severity of which appear to be related to the nature and extent of the primary brain dysfunction.

Steeves (1983) recognised that there had been no experimental studies on the 'potential role of memory in the output efficiency of dyslexic children on tests of computation'. She chose subjects of average or above average intelligence aged between 10 and 14 years. Through experience, Steeves had recognised that some dyslexic children showed a talent for mathematics whilst also exhibiting weak computation skills. The Raven's Standard Progressive Matrices provided a measure of abstract reasoning for the dyslexics, indicating mathematical potential. Twenty-seven subjects were selected from the dyslexic group that had scores at or above the 90 percentile and termed the DH group. This group was matched on age and sex with 27 dyslexics (the DA group) who scored at or below the 50 percentile. Non-dyslexic subjects were chosen to match the dyslexics on age and sex. They were chosen from accelerated mathematics programmes (NH group) and average mathematics classes (NA group). The dyslexic children scored significantly lower than their non-dyslexic counterparts on computation and the performance of the DH group was similar to that of the NA group. On the Wechsler Memory scale the DH group scored 'below the norm in logical memory, memory span (both forward and backward), and easy and hard tests of associate learning' thus contributing to the conclusion that the memory skills of the dyslexics (both groups) were inferior to those of the non-dyslexics.

Evidence from Miles (1993) showed that 'almost all' the dyslexic subjects had difficulty in reciting multiplication tables. Even at the age of 11 years the dyslexic subjects had difficulty reciting the 2, 3 and 4 multiplication tables. Miles noted that they frequently: lost their place during reciting and asked where they had got to, left out the 'preamble' (e.g. 'One seven is ... ', 'Two sevens are ... ', etc.), made consistent errors by still applying the rule, 'for example, if, having said that six threes were twenty, the subject...said that seven threes were twenty-three', broke into the wrong table (e.g. 'Six sevens are forty-two, seven sevens are forty-nine, eight eights are sixty-four'), reoriented themselves by repeating an earlier product ('epanalepsis'), made appreciable pauses, slipped up (e.g. 'eight eighties, I mean eight eights') or made a skip from 'six eights to eight eights'. Of a sample of 80 dyslexics aged between 9 and 12 years, 96% 'stumbled' when reciting their 6×, 7× and 8× tables. These errors indicated memory overload.

On subtraction some dyslexics had used their fingers, drawn marks on paper, resorted to 'unusual strategies', confused the order of the numbers (e.g. in response to 9 – 7 had said 'I took 9 away from 7'), requested repetition of the question and showed uncertainties over the order of numbers and over left and right when performing calculations. Miles (1993) states that:

> When one looks at the attempts of dyslexic subjects to do subtraction and addition, the overall picture is often that of a highly sophisticated person, well capable of quite complex logical reasoning, who is nevertheless severely restricted in his ability to give instant answers, and who therefore has to resort to strategies – often of his own devising – which are time-consuming and may sometimes involve considerable risk of error. (p. 123)

Both a Tables and Subtraction sub-test are included in the Bangor Dyslexia Test devised by Miles (1982, 1997).

In an experiment designed to test for knowledge of number facts, Pritchard et al. (1989) compared the performance of 15 dyslexic boys aged between 12 and 14 years with controls matched on age and SPM score (Raven Standard Progressive Matrices). The subjects were asked for answers to all the products from 2 × 2 up to 16 × 16. One point was awarded for an answer that did not require calculation (thus termed a 'number fact') where an answer could be given instantly or 'in one'. Out of a maximum possible score of 225, the dyslexic scores ranged from 109 to 39 whereas the scores for the controls ranged from 156 to 78. There was a statistical significance ($p < 0.001$) between the groups in favour of the controls and therefore the dyslexics had fewer number facts available to them than the controls. Inspection of the performance on individual tables showed that the dyslexic made particular use of patterns or regularities within the tables (e.g. on the 2×, 5×, 10× and 11×) as a consequence 'of their weakness in memorising number facts'. The order of multiplication number facts by table for the dyslexics was: 10, 2, 11, 5, 3, 4, 6/7, 8, 9 and 12 from most to least.

A paper entitled 'Speed of Multiplication in Dyslexics and Non-dyslexics' by Turner Ellis et al. (1996) was presented as a prelude to the present research. The method and findings are contained within this thesis.

Miles et al. (2001) conducted the first large-scale study of mathematics and dyslexia on 12,131 ten-year-old children, born in England, Wales and Scotland from April 5 to 11 in 1970. A 'Friendly Maths Test' (FMT) containing 72 items in multiple-choice format (5 choices) was given in untimed conditions. A group of 269 children, out of the grand total, were identified as containing 'a large proportion of typically dyslexic children'. The results showed that 'Despite the absence of differences in intelligence level, the mean score on the mathematics test for the dyslexics was not only lower than that of the normal achievers but lower also than that of underachievers believed not to be dyslexic' (p. 299). In 13 of the items, the difference in pass rate between the dyslexics and normal achievers was 20% or more. These items included subtraction, multiplication, division with borrowing or regrouping, finding the smallest decimal number, fractions, the unit of area and mathematical vocabulary.

In addition 19 judges, experienced in teaching mathematics to dyslexics, rated each item from 1 (easy) to 5 (hard) in relation to how they perceived a ten-year-old dyslexic would fare, giving reasons for their choices. A study of the ratings showed statistical unanimity in response. Judges commented particularly on aspects of the test that would challenge the memory weakness of the dyslexics: 'First, the comments on questions 8, 12, 13 and 15 make very clear that memory problems seriously impede the progress of dyslexics in mathematics'. This led them to the conclusion:

> That the great majority of dyslexics have problems of immediate memory is now well established and is probably a consequence of their phonological difficulties, their slowness in processing speech sounds. Our data show very clearly how these difficulties affect their performance in mathematics. (Miles et al., 2001, p. 314)

1.8.4 Teaching Mathematics to Dyslexics

There are a number of practitioners in the field of dyslexia and mathematics in education that have published work. A selection of authors and titles include (books in italics):

(1) Street (1976) – 'Sequencing and Directional Confusion in Arithmetic'
(2) Burge (1986) – *Dyslexia – Basic Numeracy*
(3) Sharma (1990) – 'Dyslexia, Dyscalculia, and Some Remedial Perspectives for Mathematics Learning Problems' (*Math Notebook*)
(4) E. Miles (1992) – 'Reading and Writing in Mathematics'
(5) Chinn (1992) – 'Individual Diagnosis and Cognitive Style'
(6) Chinn and Ashcroft (1992, 1998) – 'The Use of Patterns' and *Mathematics for Dyslexics – A Teaching Handbook*
(7) Henderson (1989, 1992, 2001) – *Maths and Dyslexics*, 'Difficulties at the Secondary Stage' and *Maths for the Dyslexic*
(8) Kibel (1992) – 'Linking Language to Action'
(9) Deveaux (1992) – 'Multiplication Tables, the Dyslexic Child, Any Child'
(10) Malmer (2000) – 'Mathematics and Dyslexia – An Overlooked Connection'
(11) Henderson and Miles (2001) – *Basic Topics in Mathematics for Dyslexics*

The reader is referred to these for more information on practical aspects.

Relevant issues of mathematics, such as mental calculation, the four mathematical operations and learning difficulties in mathematics, are reported in the following section.

1.9 Relevant Mathematical Knowledge and Research

1.9.1 Mental Calculation

Mental arithmetic is considered to be one of the most important aspects of the mathematics curriculum in schools for four main reasons: 'Most calculations are done in the head rather than on paper ... Mental work develops a sound number sense ... Mental work develops problem-solving skills ... Mental work promotes success in later written work' (Thompson, 1999, ch. 12). Mental calculation involves two main aspects: knowing number facts and working/figuring out.

A main challenge facing researchers is to find out how children perform mental calculation and if there are any aspects about number that affects their performance.

One way to determine quantity is to count, which by definition is: 'a process in which the objects in a set are noted one at a time, each object being noted once and only once. Further, as each object is noted, it is paired with a word (a number name) and these words are named in a fixed order ("one, two, three ...")' (Resnick and Ford, 1984, p. 69). Gallistel and Gelman (1992) propose that counting is innate and that cognitive processes for dealing with numerosities and magnitudes 'were already present in the remote non-human ancestors from which we ... descend'. Similarly, Butterworth (1999) contends that 'We are all born with a Mathematical Brain – a brain that contains a special Number Module that categorizes the world in terms of numerosities and forms the basis for our concept of numerosity'. Dehaene (1997) sums up a longstanding debate on counting, by stating:

> The truth, which is being progressively unveiled after years of controversy and tens of experiments, seems to stand somewhere between the 'all innate' and the 'all acquired' extremes. Some aspects of counting are mastered quite precociously, while others seem to be acquired by learning and imitation. (p.119)

1.9.2 Addition and Subtraction

There has been increasing interest in the cognitive processes that underlie mental calculation skills.

Groen and Parkman (1972) investigated how children and adults solved single-digit addition problems. They proposed five counting models and asked 37 children in first grade to add two numbers whose sum was less than or equal to 9. The children pressed one of ten buttons marked from 0 to 9 for each of 55 questions. An evaluation of the five models was based on a study of the response latencies for correct responses. The most successful model (called the 'min' model standing for minimum addend) was based on the child choosing the greater of the two presented numbers, onto which was to be added the lesser (minimum) of the two numbers in increments of one. An 'auxiliary register' would be needed to keep account of the number of increments. Ties (e.g. 2 + 2, 3 + 3) were answered more quickly than any other problems with the same minimum number and the researchers attributed this to memorisation, stating that:

> It might be that the subject has the response stored in long-term memory and uses some type of fast retrieval algorithm in order to find the correct response. The important point is that it is assumed that whatever process is responsible for retrieving the correct responses takes a length of time that is short compared to the length of time required to generate that same answer by means of a computational procedure, and is independent of the magnitude of the number being retrieved. (p. 335)

Woods et al. (1975) conducted a similar experiment on 40 second- and fourth-grade children, this time proposing five process models for subtraction. The response to 54 single-digit subtraction problems showed that a process of incrementing and decrementing was used based on a decision as to which was faster. If the two digits were close in value (e.g. 9 – 7) the subjects favoured an adding response to reach a solution (e.g. 7 + ? = 9) and used subtraction if the digits were far apart in value. The older children were found to take 'only about half as much time for each increment or decrement as the younger' attributed to a 'developmental trend in speed of processing'.

An important distinction was made between the use of counting and memory retrieval in mental arithmetic by Ashcraft and Fierman (1982), for they suspected that incrementation models would not explain the declarative methods demonstrated by adults. They sought 'to determine the age at which performance shifts from counting to retrieval' by examining the responses made by third, fourth and sixth graders to 100 single-digit addition problems (from 0 + 0 through to 9 + 9). They found that half of the third-grade children used counting processes similar to that proposed by Groen and Parkman (1972), whilst the other half of the third graders resembled the two older grades studied, consistent with the notion of memory retrieval. Thus they concluded that 'third grade is a transitional age for mental structure for addition – some children show evidence of memory retrieval at this age, whereas fourth graders seem to have this structure fairly well integrated into their information processing strategies' (Ashcraft and Fierman, 1982, p. 232). In response to these findings, Miles (1993, p. 120) commented on the results of his investigations on dyslexics, stating that 'It is therefore noteworthy that some of my subjects were still relying on counting at age 14 and later'.

Children do not always use the optimum strategy or apply a uniform approach as implied by the models. The structure of the problem can influence the process adopted and this structure can vary within a mathematical operation. Thus a search for consistency or widespread use of strategy choice can prove illusive (Carpenter and Moser, 1983).

Consistent patterns of response are found for faster reaction times to ties and smaller addends (the problem size effect) where, for example, 7 + 9 is more difficult than solving 3 + 4 both for speed and accuracy (Hamann and Ashcraft, 1985).

1.9.3 Addition and Multiplication

Winkelman and Schmidt (1974) used the term 'associative interference' whereby numbers can be associated in a range of ways. They claimed that these associations caused interference in mental arithmetic with slower reaction times and more errors on single-digit addition and multiplication problems:

> It is proposed that there exist associations between pairs of digits and both their sums and products; for example the digit pair (3, 3) would have associations with both 6 and 9. The obvious prediction is that stimuli of the type $3 + 3 = 9$ and $3 \times 3 = 6$ will produce a tendency to respond 'yes' because of associative interference. (Winkelman and Schmidt, 1974, p. 734)

Such interference effects were incorporated into a network retrieval model proposed by Stazyk et al. (1982) for both addition and multiplication. According to this model, adults store addition and multiplication facts in a network structure that is organised like a printed addition or multiplication table. For addition the sum of two numbers is stored at the intersection of a row and column, 'accessed by a process of spreading activation'. For example, when adding $6 + 3 = 9$, activation would spread from 6 and 3, intersecting at the sum 9. The time taken for this search process would be 'a function of the distance travelled through the network'. Nodes represent the stored answers to the problems. For multiplication: 'Retrieval of a fact consists of a spreading activation search beginning at the parent nodes (the problem's multipliers) and resulting in an eventual intersection at the node representing the correct answer' (pp. 322–3). To account for interference across addition and multiplication problems, Stazyk et al. (1982) suggested that the addition network could be activated even during multiplication (e.g. $3 \times 4 = 7$).

1.9.4 Multiplication and Division

For many years in mathematical research, the notion of ease of acquisition of arithmetic skills was based on how large the numbers involved were. The larger the numbers the harder the sum would be. This was commonly known as the problem-size effect. In an experiment focussing on response time and errors on multiplication problems up to 9×9, Campbell and Graham (1985) disputed the general problem-size rule when they found that their subjects responded faster on the 5-times table than the size would have predicted. Similarly the 9-times problems tended to be responded to faster than the 8-times problems. Instead, the problem-size effect 'is largely the result of large-number problems being tested less often and occurring later in the learning sequence, factors that result in relatively weak correct associations and more, or stronger, competing associations' (p.359). They cite 4×8 (or 8×4) as an example of a difficult problem since it is strongly associated with 24 where both 4 and 8 have 'correct multiplicative associations with 24' as well as $3 \times 8 = 24$ being similar. On the other hand, 8×9 or 9×8 is an easier problem since the product (72) is not 'embedded numerically among other candidate answers' since it is the only simple multiplication product to be found in the seventies, therefore it can be discriminated from other answers, enabling ease of retrieval and learning. Errors were therefore found to be products which would have been correct for other sums and that competing associations hindered accessibility to correct answers. Campbell (1987) stated in a following paper that '... arithmetic retrieval errors can be understood as intrusions by false associations and that correct RT [response time] is influenced by the strengths of false associations'.

LeFevre et al. (1991) suggested that 'distance' or the proximity of neighbouring numbers along a number line created additional potential interference. The strength of number line connections was greater for children than adults indicating their greater reliance on counting strategies. For efficient, speedy and automatic retrieval of number facts, successful inhibitory processes are required to overcome contradictory associations such as, '... the numbers 3 and 4 are associated with 5 (counting string), 7 (addition), and 12 (multiplication)'.

Rickard et al. (1994) recognised the potential for transfer of learning from multiplication to division. They suggested that '... performance on some division problems may have been mediated by multiplication knowledge, with a transition to direct retrieval of division facts as skill improves'.

1.9.5 Number Processing and the Four Operations

A triple-code model for numerical cognition is postulated by Dehaene (1992) showing that numbers can be mentally represented in an: 'analog, magnitude representation' enabling subitising, estimation, comparison and approximate calculation; 'auditory, verbal word frame', e.g. 'thirteen', incorporating language processing, written input and output, auditory input and spoken output and addition and multiplication tables; and a 'visual, Arabic number form', e.g. '13' for numeral reading and writing and multidigit operations. Internal translation processes are possible between each code.

Dehaene and Cohen (1995) proposed that a variety of strategies used in learning could account for a wide range of neurological findings (dissociations) on brain damaged patients whilst performing mathematical tasks.

> The four basic operations of addition, multiplication, subtraction, and division, as taught at school, obviously put different emphasis on memory, semantic elaboration, and backup strategies. For multiplication, rote memory retrieval is the main strategy ... Many simple additions are also memorised, but semantic elaboration and backup counting strategies are also available. Finally, subtraction and especially division are much less routinised and may be solved by counting or even by an 'inversion' strategy of searching in memory for the converse addition or multiplication fact (e.g. 45/9 is solved by searching the 9 times table and retrieving $9 \times 5 = 45$). (p. 106)

A selection of neurological studies based on number processing and calculation, can be found in: McCloskey et al. (1991), McCloskey (1992), McNeil and Warrington (1994), Cipolotti and Butterworth (1995) and Chochon et al. (1999).

1.9.6 Mathematics and Learning Difficulties

Reference is next made to a number of studies that include the findings for children and adults who are learning disabled. In some cases the links with dyslexia are not clear due to the use of differing terminology (such as the use of the word dyscalculia) and reasons for choice of subject. However, these studies have been included because of their potential relevance and importance.

Košč (1974) identified children with 'developmental dyscalculia' and stated that nearly 6% of all children showed symptoms of this disorder. The identifying features, that resemble those found in dyslexia, include: lexical dyslexia – a disability in reading mathematical symbols, graphical dyscalculia – a disability in manipulating mathematical symbols when writing, ideognostical dyscalculia – having difficulty with understanding mathematical relations, ideas and in doing mental calculation and operational dyscalculia – interchanging operations: '... doing addition instead of multiplication; subtraction instead of division; or substitution of more complicated operations by simpler ones (e.g. $12 + 12 = (10 + 10) + (2 + 2)$)'. In some cases calculation is performed by counting on the fingers 'where the task could be easily solved silently'.

Lewis et al. (1994) claimed that the proportion of 9- to 10-year-olds within a sample of 1,206 British schoolchildren was found to be 1.3% with specific arithmetic difficulties, 2.3% with a combination of arithmetic and reading difficulties and 3.9% with specific reading difficulties. A discrepancy in proportional figures compared to the findings of Košč (1974) may be explained in terms of the use of different tests of attainment, ability levels and 'cutpoint' criteria (p. 290). Ramaa and Gowramma (2002) showed that of 1,408 Indian children aged 7 to 9 years of age, 5.54% (78 children) displayed the presence of dyscalculia. Of this number, 51.27% (40 children) also had reading and writing problems.

Several researchers write of the co-occurrence of reading and mathematical disabilities (Ackerman et al., 1986; Geary, 1993; Lyytinen et al., 1994; von Aster, 1994; Ackerman and Dykman, 1995; Shalev et al., 1995; Gross-Tsur et al., 1996; Geary et al., 1999; Badian, 1999; Montis, 2000; Ramaa and Gowramma, 2002). Lyytinen et al. (1994) stated that 28% of children referred to his clinic had problems with both reading and mathematics and Shalev et al. (1995) indicated that dyslexia was found in 17% of children with developmental dyscalculia. Ackerman and Dykman (1995) found that students with co-occurring reading and arithmetic disabilities showed processing speed as a core weakness, as well as other possible factors, such as 'inferential reasoning, generalization, temperament, and inadequate supervised practice'.

Rourke and Finlayson (1978) compared the performance of a group of 9- to 14-year-olds with reading, spelling and arithmetic learning disabilities combined (Group 1), with that of a group of similar aged children with just arithmetic difficulties (Group 3). The performance of Group 1 was superior to that of Group 3 on measures of visual-perception and visual-spatial abilities. Conversely Group 3 was superior on measures of verbal and auditory perception. In an adjoining study, Rourke and Strang (1978) found that Group 3 was weaker on general psychomotor coordination and tactile discrimination such as finger agnosia. The pattern of behaviour by Group 3 was likened to Gerstmann syndrome, which will be detailed later.

Fleischner et al. (1982) undertook a comparison study of what they called 'learning disabled' (LD) and nondisabled children in grades 3 to 6 (from 8 to 12 years of age) on basic fact problems (single-digit) in addition, subtraction and multiplication. The number attempted in a three-minute trial was on average the same for the LD children in grade 6 as the nondisabled children in grade 3. 'No indication was found that nondisabled children used overt counting to arrive at the solution to problems, whereas a substantial number of LD children had worked out the problems by making lines, or marks, and apparently, counting them' (p. 54). Such an approach appeared to have slowed down computation speed. In addition, the LD group made more errors and showed greater variability in performance and both groups improved in accuracy with age. Both groups also displayed greater speed and accuracy on addition, compared to subtraction.

Case reports on 12-year-old identical male twins were reported by Temple (1994). They displayed 'number fact dyscalculia' – which presumably means a specific difficulty with acquiring number facts for calculation. It is possible that Temple was describing the difficulties experienced by dyslexic twins. The parents referred their sons because of 'persisting written language difficulties'. Full-scale IQ figures for the twins were given as 136 and 145 with spelling at 20 months below reading age in the case of one son, and 'over 18 months below the level expected from his chronological age' for the other son. The following conclusions were drawn from this particular case study:

> 1. Number fact knowledge is distinct from procedural knowledge and number processing.
> 2. There can be selective impairment of number fact knowledge despite intact development of procedural knowledge.
> 3. If arithmetic develops in stages, procedures precede facts.
> 4. Errors can be rule governed and logical.
> 5. Accuracy of response is not equivalent to normal performance, since it may reflect reconstruction of facts rather than retrieval of facts.
>
> (Temple, 1994, p. 367)

The issues raised in this section involve elements in the wider field of mathematics that are relevant to the mathematical tasks given to the participants in the present research. Research has also been presented in 1.9.6 that indicates the co-occurrence of literacy and mathematical difficulties.

Part 3: Other Aspects of Dyslexics' Performance

1.10 Additional Behaviour

Part 3 outlines behavioural, emotional and motivational factors that may be influential on the dyslexics' performance on the mathematical tasks in this research.

1.10.1 Bodily Movements

It is possible that dyslexics approach tasks with a different form of behaviour than non-dyslexics. MacMeeken (1939) reported on 'the intense effort' that aphasic children displayed when recognising words. Her description of the aphasic child is similar to what we know as dyslexia today. Further she stated: 'Such effort is in many cases accompanied by exaggerated tongue and lip movements, movements of the head, facial grimaces, even by other body movements, say, of arm or leg' (p. 25). MacMeeken drew attention to 'how' tasks were performed; what movements were made in the execution of tasks, including expressive hand movements. Miles (1993) refers to the work of MacMeeken as an important influence on his thinking.

1.10.2 Verbalisation

Despite Torgesen and Goldman (1977) producing evidence that reading-disabled children use the strategy of verbalising less than normal, there are reliable accounts from Miles (1993) that dyslexics readily verbalise, as in the case of scoring the 'crikey' (see 1.7.4 for more details). Verbalisation can act as a 'prop' to counteract memory difficulties, such as asking for a question to be repeated, repeating the instruction to oneself or using the response of epanalepsis whereby reorientation is attempted by going back to a previous cue, such as starting again at January when attempting to say the months of the year, in the hope that the correct sequence will emerge afresh. Miles and Ellis (1981) report on confusion over writing the number 16 in that the six may be written first because that is what is said first. Baddeley and Hitch (1974) view verbalisation as a way to prevent the decay of information in the articulatory loop (see 1.5.4 for details). There have been few studies on the verbalisation behaviour of dyslexics during tasks in the light of MacMeeken's (1939) interest in 'how' tasks are performed. This is quite apart from articulation issues (see 1.4 for more details).

1.10.3 Fingers

Etymologically number names originate from words for fingers and hands, such as 'five' as the word for hand and 'digit' related to a finger. Fingers are '(literally) handy. They are usually not covered by clothing; they are readily visible to the counter and any audience; they are moveable and manipulative (again, literally)' (Butterworth, 1999). Butterworth refers to a connection between finger agnosia and acalculia in Gersmann's syndrome (see 1.10.4), proposing that finger representation in the brain corresponds to the development of number skills. Children practise counting on their hands, and counting numbers gradually become associated with finger movements and positions that are represented in the brain.

The use of fingers in mental calculation provides clues as to the mental methods being employed whilst providing 'tactile and visual support' for the user. The strategy of finger usage in calculation is more complex in multiplication than for addition or subtraction, because 'the two numbers have differing roles: one represents the number of items in a set, whereas the other represents the number of such sets' (Anghileri, 1997).

In the context of a lexical encoding deficiency in dyslexia (see 1.3.3 for details), Miles and Ellis (1981) referred to the 'need for concrete representation' by dyslexics when counting. This took the form of using fingers or making marks on paper, noticed especially where more than five was being subtracted in a problem. Using fingers is a way of keeping hold of the process physically and freeing up the mechanism of working out, thereby lightening 'the load of material which has to be lexically encoded'. The strategy of 'doing' reinforced the weaker aspect of 'naming'. Miles (1993) presented the case of 'John' an 8-year-old dyslexic. A letter received from an educational psychologist reported that 'John's number work is still behind. He takes a long time to work out very simple additions and subtractions and unless he used his fingers he frequently made errors when adding single-digit numbers' (p. 30). In addition Miles (1993) observed compensatory strategies such as the use of fingers on such questions as 19 – 7. It was reported that 29 dyslexic subjects had clearly used their fingers for subtraction and one had reported using his toes. A reliance on counting was evident beyond the age of 14 years and even at 18 years. This is in comparison to the finding of Ashcraft and Fierman (1982) that most children move from counting to retrieval at about the age of 9 years. Also Pritchard et al. (1989) referred to the use of fingers in calculation by dyslexics. That numbers 'go up in ones' is a regularity upon which dyslexics rely, especially when using their fingers.

The use of the tactile sense is reported by Jansons (1988) in a personal account of his dyslexia. As a talented mathematician he states that he prefers not to think in words and apart from the use of visualising strategies, he resorts to remembering, for example how to tie a complicated knot, by imagining the sequence of movements on his fingers and the feel of the knot. This is an example of his ability to manipulate his thinking in three-dimensional space.

Despite the observed reliance on fingers when calculating, Wolff et al. (1990) showed that dyslexics aged from 13 to 32 years displayed great difficulty in maintaining correct 'timing precision on bimanual tasks that required the integration of asynchronous responses, but not when they moved the fingers in unison'. The subjects had been asked to tap their index fingers in specific time with a metronome. The dyslexics had been matched with normal control subjects (by sex and age) but it was considered a limitation of the study that 'neither young dyslexic nor reading-age-matched normal control children were examined'. However it was hypothesised that the difficulty seen on bimanual tasks requiring asymmetric or asynchronous responses was due to the failure to inhibit interfering and unintended mirror movements (see 1.7.4 for further details on inhibition).

There is evidence that hand usage and verbalisation may be developmentally related. Ramsay (1984) showed that the onset of unimanual handedness in infants occurred within the same week as the onset of duplicated syllable babbling. This temporal correspondence indicated simultaneous reorganisation of the control of vocal and manual functions.

Reference to the use of fingers is also made in the following section.

1.10.4 Bodily Awareness

In 1940 an American neurologist called Gerstmann published a special article on the 'Syndrome of finger agnosia, disorientation for right and left, agraphia and acaculia', which was to become known as Gerstmann syndrome. Finger agnosia was described as a disability in 'recognizing, naming, selecting, differentiating and indicating the individual fingers of either hand, the patient's own as well as those of other persons' with the three middle fingers being the most affected. The fingers lacked a freedom of individual action. Confusion of left or right was found when the patient was asked to point to 'contralateral parts of the body'. A similar task was designed as part of the Bangor Dyslexia Test (Miles, 1982, 1993, 1997). Agraphia referred to difficulty with spontaneous writing and writing when dictated to. Acalculia was a difficulty with performing calculations, such as lacking an appreciation of place value (e.g. in decimal numbers), and disorientation with the order of digits within a figure. The four main symptoms were found to group pathologically to a lesion in a specific region of the brain. Gerstmann advised that a difficulty in any one of the four symptoms should prompt an investigation of the other three symptoms. Other various clinical symptoms may also accompany the main four: loss of memory in finding words, a difficulty in reading, disorientation with time, impaired perception of colour, and a 'disturbance of equilibrium'. The difficulty with calculation was proposed to be a 'prerequisite for proper orientation in time'. These symptoms are remarkably similar to those for dyslexia and it is noteworthy that mathematics is involved.

Hermann (1956) sought to clarify the relationship between poor readers and Gerstmann's syndrome and showed that the two originate from the same functional disturbance. He recognised that 'reading-writing difficulties are often complicated with asymbolia in other fields (numbers, notes, Morse code, semaphoring, shorthand, metric symbols, etc.)'. Hermann wrote of the 'striking accordance' between the types of errors found in congenital word-blindness and Gerstmann's syndrome, for example the writing to dictation of the number 1,548 as 1000548 and the high prevalence of right–left and finger naming confusion in word-blind persons. Other researchers, including Johnson and Myklebust (1967), Vellutino (1979), von Aster (1994) and

Miles et al. (2001) referred to the association of this syndrome with dyslexia although Critchley (1970) raised doubts.

Pontius (1983) suggested a link between 'pictorial (and implied mental) misrepresentation of the fingers and low skills in numerical calculation' by remotely located New Guineans and Indonesians. The existence of Gerstmann syndrome was evoked in this study and additional information was given on the paucity of facial representation in the drawings of these groups, representing poor body schema as well as weak literacy skills. There is a similarity between this last finding and that of Griffiths and Frith (2002) in that dyslexics were shown to have poor articulatory awareness for the facial positions required to produce particular sounds.

Karádi et al. (2001) found that dyslexics had poor representation of space in relation to their own bodies in respect of right–left orientation. An egocentric mental rotation task was given to dyslexic children of mean age 9:2 years and comparisons were made with non-dyslexics of mean age 8:8 years. The task required an egocentric reference frame. The task was to indicate whether the right or the left hand was presented in a picture. The angles of right- and left-hand presentation were 0, 50, 90 and 180 degrees. The dyslexics took longer to respond and made more errors.

1.11 Emotional and Motivational Factors

1.11.1 Stress

Critchley (1970) pointed out that the performance of a dyslexic was likely to deteriorate when under 'circumstances of emotional stress' (p. 32). Several accounts of stress experienced by dyslexics are given in Miles and Varma (1995).

1.11.2 The Matthew Effect

Stanovich (1986) referred to the depletory cumulative effect of difficulty in learning to read. This he termed the 'Matthew effect'; the name is taken from the Gospel according to Matthew (XXV: 29) which reads: 'For unto everyone that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath'. Within the reading context, if one is initially a poor reader then as time goes on one falls further behind. Progress in reading, for example, can lead to a cumulative advantage of increased motivation, rewards, productivity, more practice, choice of reading as a leisure activity and improvement of current knowledge with possible acceleration of progress. Similarly Joffe (1981), in her literature review, found that most studies supported the view that 'a positive attitude and satisfactory self-concept are associated with competence at least, and perhaps excellence' in mathematics. Stanovich (1986) reported, conversely, that in the case where reading acquisition is not so easily achieved, a detrimental cumulative effect may occur; poor vocabulary, less words read, slow reading, lack of motivation, low self-esteem in adult life (Riddick et al., 1999), low productivity, lack of enjoyment, less practice, reading for shorter periods, slow rate of reading growth, less rewards and fewer books present in the home environment and anxious mothers/parents (Jansons, 1988). The 'motivational side effects' may include a generalised helplessness, which pervades into other areas of a person's life, such as in other academic subjects, eroded general feeling of well being and confidence, giving up easily and less task persistence – the very qualities needed to counteract the difficulties. Stanovich stresses the importance of breaking this undesirable cycle through better and more specific identification, relevant and informed teaching on the problem and early intervention. There is an issue of direction of causality concerning morale/motivation. Help the dyslexic in mathematics and this could help the self-confidence to improve. It is not necessarily the case that by helping the self-confidence the mathematics will improve.

Ackerman and Dykman (1995) referred to the 'Matthew effect' when studying the performance of reading/arithmetic disabled students from 8 to 17 years of age. They proposed that the 'Matthew effect' 'may be more pronounced in arithmetic than in reading' (p. 365).

1.11.3 Anxiety and Mathematics

Ashcraft and Faust (1994) and Ashcraft (1995) reported on the effects of anxiety on mathematical performance. Ashcraft and Faust (1994) define mathematics anxiety as: 'a feeling of tension, apprehension, or even dread that interferes with the ordinary manipulation of numbers and the solving of mathematical problems' (p. 98). Higher maths-anxious subjects, tested on a Mathematics Anxiety Rating Scale, were particularly slow on an effortful mental arithmetic task involving addition with carrying (complex addition). In contrast the low anxiety group were 'considerably faster, and also more accurate' than the high anxiety group. On other questions taken from the four operations (such as simple addition and multiplication), an 'anxiety induced speed-accuracy tradeoff' (Ashcraft, 1995) was found where the high anxious subjects responded as quickly as the low anxious subjects, but were far more error prone. This was thought to reflect an avoidance of the 'potentially distressing math stimuli' (Ashcraft and Faust, 1994) thereby avoiding involvement in the task or choosing to give the minimum amount of attention to the task. It was also suggested that high anxious students tend to adjust their answers frequently because they are less certain of their accuracy. This leads to less fluency in calculation and less overall development of the understanding of the relationships between numbers. Ashcraft and Faust (1994) speculated that because anxiety had such a disruptive effect on such 'relatively commonplace computations' then anxiety disruption would have a 'pervasive' effect throughout the student's whole understanding of number.

Steeves (1983) warned of the dangers of not recognising the needs of gifted children by appropriate help in school. Within this group, Steeves included dyslexics with high reasoning ability, despite their having difficulties with computation. Such children may show frustration, become under-achievers or even drop out of the educational system altogether. Steeves disagreed with the emphasis placed on computational efficiency as a way of gaining access to professions that require such qualities as: 'spatial ability, clear thinking, and logic'.

1.11.4 Personal Approach Towards Tasks

Siegler (1988) maintained that mathematical performance in young children was influenced by personal approach towards tasks. He examined individual differences in strategy choice by 6-year-olds when performing addition, subtraction and word identification tasks. He found that there were two main factors that contributed to strategy choice: 'peakedness of distributions of association and the stringency of confidence criteria'. Taking the question '2 + 1' as an example, the first factor refers to a strong associative strength registered for the answer 3. If plotted on a line graph with associative strength on the 'y' axis and answers arranged in a number line format from 1 to 10 on the 'x' axis, the graph would register a peak in associative strength at the answer 3 with low associative strength found for the answers 2 and 4 on either side of 3. However, the graph for '3 + 5' would show a flat distribution with higher associative strength on several numbers such as the answers 6, 7 and 8. The confidence criterion was described as the threshold in associative strength of a retrieved answer (set by the child) beyond which an answer would be given. Children with more peaked distributions were able to answer more often, and with greater accuracy and speed, than children with flat distributions. The latter were found to use backup strategies more often, such as counting on their fingers. The response pattern of the children enabled the researcher to identify three types of student: 'perfectionists, good students, and not-so-good students'. The perfectionists showed peaked distributions but set themselves very high confidence criteria, the good students also showed peaked distributions but had lower confidence criteria whereas the not-so-good students had less peaked distributions than the other two groups and also had low confidence criteria. These factors therefore had an influence on the success of the student.

In conclusion, the main factors that can potentially influence the performance of dyslexics are: additional behaviour such as bodily movements, verbalization, use of fingers; bodily awareness; emotional and motivational factors such as stress, the Matthew effect, anxiety in relation to mathematics and personal approach towards tasks.

1.12 Chapter Summary

The literature review is presented in three parts that essentially focus on: perspectives on dyslexia; research on dyslexia and mathematics including relevant mathematical knowledge and research; and other aspects of dyslexics' performance.

The review of dyslexia in Part 1 includes particular reference to dyslexia as a concept as well as emphasis on five aspects of research and knowledge. These are: paired associate learning and verbal encoding, articulation, memory, the issue of delay or deficit in dyslexia and responding at speed. These aspects were chosen because of their relevance to correctness and speed of performance in dyslexia.

The focus of Part 2 is on dyslexia and mathematics including reference to specific research in this field as well as knowledge available for practitioners. A further review is given of relevant mathematical knowledge and research. A central theme of Part 2 is that of the four operations.

Part 3 focuses on other aspects of dyslexics' performance including additional behaviour, such as bodily movements, verbalisation and use of fingers. The last section under this heading is entitled 'Bodily Awareness'. This section includes a review of relevant literature on the Gerstmann syndrome, which has been presented under this heading primarily because of its association with finger agnosia. This syndrome is of added interest because it includes a further symptom concerning difficulty with performing calculations. Part 3 concludes with a review of emotional and motivational factors that could have a bearing on the performance of dyslexics in mathematics.

Chapter 2 follows with details of the central research questions that shape the remainder of the thesis.

CHAPTER 2

The Interesting Questions

2.1 Introduction

2.2 Aspects of Mathematics That can be Challenging for Dyslexics

2.3 The Origin of This Research

2.4 Informal Observations

2.5 Interesting Questions

2.6 This Research Addresses Eight Questions

2.1 Introduction

One of the issues that has been found in literature is that dyslexics have difficulty with mathematics. This is particularly apparent in the practical literature (see Chapter 1 section 1.8.4 for further reading). Yet despite this emphasis, a substantial body of relevant research on dyslexia and mathematics (37 papers) is not evident in marked contrast to the greater number of investigations that have occurred historically in connection with dyslexia and literacy (over 3,400 papers).

2.2 Aspects of Mathematics That can be Challenging for Dyslexics

Mathematics, per se, is a broad subject with a multiplicity of aspects. In order to select which questions about dyslexia and mathematics are most worth asking, it is necessary to narrow the focus and concentrate on those facets that are most relevant. As a starting point, the following is a selection of those aspects of mathematics that have been recognised by practitioners and researchers as being a challenge for dyslexics:

(1) knowledge of multiplication number facts (Joffe, 1981; Pritchard et al., 1989; Miles, 1993; Chinn and Ashcroft, 1998; Henderson, 2001; Henderson and Miles, 2001);

(2) performing mental calculation with subtraction that crosses the ten-barrier (e.g. 44 – 7) (Miles, 1982, 1997);

(3) carrying errors (Joffe, 1981, p. 304);

(4) weakness over calculation in general (Miles, 1993) or lack of computational efficiency (Steeves, 1983);

(5) confusion with mathematical symbols, for example the sign '+' can be mistaken for '×' or likewise '–' can be confused with '÷' (Chinn and Ashcroft, 1998) and also terminology (E. Miles, 1992), for example 'take away' might for some children have associations with a Chinese take-away;

(6) difficulty in learning basic number facts and consequently failing 'to develop an understanding of the values and interrelationships of numbers' (Chinn and Ashcroft, 1998, p. 35), such as number bonds, place value (Malmer, 2000), basic facts for addition and subtraction, times tables for both multiplication and division;

(7) reading numbers accurately (Henderson and Miles, 2001, p. 5).

(8) counting forwards and backwards (Henderson and Miles, 2001, p. 5).

The overriding theme is one of number difficulties in connection with the four basic mathematical operations. Mathematical learners are required to develop a number sense built upon the use of addition, subtraction, multiplication and division, which constitute the foundation skills of calculation and many other forms of mathematics, e.g. decimals and fractions. This pervasive theme in mathematics and its connection with the difficulties experienced by dyslexics provided the basis for the present research.

2.3 The Origin of This Research

Pritchard et al. (1989) found that dyslexics aged from 12 to 14 years knew fewer answers to multiplication sums 'in one', without the need for calculation, than a group of age-matched controls. This is what they called knowledge of number facts. Many adults are able to respond 'in one' to $7 \times 7 = 49$ but would need to resort to calculation for 15×23. It is possible, therefore, that the threshold at which working out becomes necessary is different in the case of dyslexics. It was this idea that formed the starting point for the present research.

The paper by Pritchard et al. (1989) had several limitations:

(1) The participants used were of a narrow age-range.

(2) The controls were matched only on chronological age and not for reading or spelling age.

(3) The ability of the participants to do a sum 'in one' was determined simply by asking them. A more objective approach would be to time their responses.

2.4 Informal Observations

The researcher, as a class and special needs teacher, has made informal observations of dyslexic students suggesting that many dyslexics have difficulty learning their multiplication tables and number facts. The researcher therefore wanted to find out in a more systematic way if there was any difference between dyslexics and non-dyslexics in their ability to respond to the requirements of being numerate or to perform calculations utilising the four main mathematical operations. It seemed likely from these observations that such findings would be important in educational assessment, teaching expectations and adaptations on the part of the teacher. It seemed possible that dyslexics might require extra time when they sat mathematical examinations.

2.5 Interesting Questions

What are the important questions to ask in research? Firstly, it would be interesting to study both correctness of response and speed of response. Are dyslexics able to answer mathematical questions on the four operations with the same degree of accuracy and speed as non-dyslexics? Are they differentially handicapped on one or both aspects? Secondly, it would be of interest to compare the performance of older children with that of younger children. Such an investigation would enable an understanding of any differences between school-aged dyslexics and non-dyslexics of different ages. Thirdly would there be any appreciable difference in 'how' dyslexics and non-dyslexics performed the mathematical tasks? MacMeeken (1939) and Miles (1993) drew attention to the importance of studying 'how' tasks were performed.

Miles (1993) stated that in failing to make and report on such observations 'one is throwing away potentially useful data' (p.18).

These initial thoughts led to the formulation of key research questions.

2.6 This Research Addresses Eight Questions

When performing mathematical operations of multiplication, division, addition and subtraction:

(1) Do dyslexics make fewer correct responses than suitably matched non-dyslexics?
(2) Do younger dyslexics make fewer correct responses than older dyslexics?
(3) Are there any special number combinations that are more likely than others to generate errors?

(4) Do dyslexics need more time than non-dyslexics?
(5) Are younger dyslexics slower than older dyslexics?
(6) Are there any special number combinations that are more likely than others to take more time?
(7) Are non-dyslexics more likely than dyslexics to be able to respond instantaneously? (This is a special case of speed.)

(8) Is the behaviour of dyslexics when responding different from that of non-dyslexics?

These questions can be subdivided as follows:

Correctness	–	questions 1–3.
Speed	–	questions 4–7.
Behaviour when responding	–	question 8.

Hypotheses:

On measures of speed and accuracy of response on the four mathematical operations, dyslexics will be disadvantaged in relation to non-dyslexics due to biological (including a cerebellar deficit), cognitive (including paired associate learning and automatisation deficit) and behavioural (including motor, memory and articulatory difficulties) factors detailed in the Literature Search.

Predictions:

1. The dyslexic participants, in comparison to the non-dyslexics, will be less accurate and take longer to respond when performing the four mathematical operations.
2. The younger dyslexics, in comparison to older dyslexics, will be less accurate and take longer to respond.
3. Special number combinations in each operation, such as multiplication and division tables without obvious algorithms and addition and subtraction categories that have high addends/subtrahends or that cross the ten barrier, are likely to generate more errors and take more time and that dyslexics will be differentially affected.
4. The non-dyslexics will respond to more questions instantaneously than the dyslexics.
5. The behaviour of the dyslexics will be different to that of the non-dyslexics when performing the mathematical tasks.

The remainder of the thesis is centred around the research questions and is arranged as follows:

Part II – Experimental Design. Details are given on participants and apparatus and method (Chapter 3), results of experimental precautions (Chapter 4) and results on those operations for which two trials were conducted (Chapter 5).

Part III – Results of the Main Experiments. The results of each of the four operations are given based firstly on the findings for Correctness (Chapters 6–9) and for Speed (Chapters 10–14) including a chapter entitled 'Instantaneous Responding'.

Question 8 from the main research questions above is explored in a separate chapter on 'Additional Behaviour' (Chapter 15).

An overall comparison of the four operations with regard to correctness and speed is made in Chapter 16.

Part IV – Discussion. This section includes two chapters. The first (Chapter 17) is a discussion of the main findings from the research and links are made with different theories of dyslexia that will have been detailed in the literature review given in Chapter 1. The second (Chapter 18) contains some practical implications that result from the findings of the present research.

Part V. This section comprises a summary and conclusions (Chapter 19).

Part II Experimental Design

CHAPTER 3

Method

3.1 Introduction

3.2 Participants

3.3 Stage 1 – The Multiplication Experiment

3.4 Stage 2 – Division, Addition and Subtraction Experiments

3.5 Apparatus

3.6 Stage 1 – Apparatus for the Multiplication Experiment

3.7 Stage 2 – Apparatus for the Division, Addition and Subtraction Experiments

3.8 The Multiplication Experiment

3.9 The Division Experiment

3.10 The Addition Experiment

3.11 The Subtraction Experiment

3.12 Statistical Tests

3.1 Introduction

The methodology on participants and apparatus is divided into two parts, Stage 1 and Stage 2. These reflect experimentation over two main time periods. Stage 1 concerns a study of multiplication number facts born of initial investigations by Pritchard et al. (1989), the rationale for which is discussed below.

Stage 2 has taken place with new participants at a later date and is concerned with experimentation on addition, subtraction and division, thus rounding off mathematical investigations into the four operations. Knowledge gleaned from Stage 1 has helped to furnish subsequent research with improvements and adjustments.

Sections 3.8 to 3.11 detail the methodology for the four experiments covering each of the mathematical operations. The Multiplication experiment is presented first since it was conducted as the initial experiment. The general layout of each experiment and the method employed is similar. This research addresses eight questions as given in Chapter 2.

The dependent variables are temporal ratio data such as *time* taken to respond to the mathematical questions including where appropriate components in this process and also categorical nominal data on the *accuracy* or otherwise of the participants' answers. The independent variables are the *three age bands* (young, medium-age and old) as well as the *experimental groups* (dyslexics, CA controls – referred to as 'controls' in the Division, Addition and Subtraction experiments, as well as the SA controls – in the Multiplication experiment). In addition there are subordinate independent variables such as *order of trial*, *table number* and *quotient.* There are also sub-groupings of tasks within each mathematical operation, such as multiplication and division tables and addition and subtraction categories that are also included in the experimental design, e.g. *crossing the ten.*

3.2 Participants

3.2.1 Groups

In designing an experiment where comparisons have to be made between dyslexics and non-dyslexics, controls matched by chronological age are included among the participants. If a difference in performance is a distinctive characteristic of dyslexics, they will also differ from controls matched by spelling age (SA controls), indicating some kind of deficit as opposed to a delay. Two control groups were therefore required.

Conventionally dyslexics are compared with chronological age controls (CA controls) and reading age controls (RA controls). The reason for this is to provide direction of causality. If dyslexics and CA controls are on a level there is no problem. But if dyslexics perform worse on some task, is this due to their poor reading? If so RA controls will be at the same level. Nicolson and Fawcett (1995) have found tasks where dyslexics scored lower than RA controls.

Many who used this methodology equated dyslexia with poor reading, but poor spelling is a much better indication. It is well known within dyslexia teaching that progress in reading skills often outstrips that of spelling, which is the more resistant to improvement after specialised teaching input. In using SA controls the intention was to look for evidence of a deficit as opposed to delay – in which case SA controls would perform better than dyslexics. To our surprise they didn't (apart from the use of the algorithm hypothesis – see Chapters 6 and 10) so it was decided to leave out SA controls for the other three operations. With regard to the direction of causality problem, if the poorer results for dyslexics were due to their slowness in reading, they would be slower in search time – so we had to build in a search time procedure for the other three operations which also measured speed of motor responses.

A spelling test was chosen rather than a reading test because it is widely regarded that children can have dyslexic-type problems and still be adequate readers (Miles et al., 1998).

It is preferable to select controls matched on spelling age rather than reading age. Although many researchers have equated dyslexia with 'poor reading', this does not do justice to the complexity of the interaction between biological abnormality, cognitive deficit and behavioural manifestations (Frith, 1995), nor to the many weaknesses other than poor reading which have been reported by Nicolson and Fawcett (1995). In addition, if dyslexics are selected only on the basis of poor reading there is a serious risk of false negatives (children who show many of the typical dyslexic signs but who have learned to read adequately). This risk is particularly large if, as in the present research, the participant population is drawn from schools that specialise in the teaching of dyslexic pupils. In contrast, in view of the indisputable difficulties experienced by dyslexics in learning to spell, any child within the age-range of the present research who turned out to be an adequate speller could for that very reason be at most only mildly dyslexic.

In Stage 2, the findings from the SA controls enabled a decision to be made to exclude them from the Division, Addition and Subtraction experiments and focus on a comparison of the dyslexic group with the CA control group (referred to as the control group in Stage 2). Another refinement was the addition of a Reading/Key Search

Reaction Time Test, included within the design for Stage 2 so as to form an experimental safeguard. This test enabled a study of whether the performance of the dyslexic participants was affected by a slower reading rate and slower motor skill level. This design enabled the experimenter to arrive at a decision as to whether or not to adapt the findings for Stage 2.

In order to minimise variables that could affect the results, the following were controlled for in both stages: age, sex, geographical location and socio-economic status. The age of participants is detailed in sections 3.3.1 (Stage 1) and 3.4.1 (Stage 2). Sex is controlled for in that the participants were only boys. The controls were from the same geographical locations (rural Southern England including schools in Somerset, Wiltshire, Berkshire and Hertfordshire). Participants were chosen from private schools to control for socio-economic status. (See section 3.2.6 for further details on the schools used.)

Stage 1

Participants were selected in such a way that they could be assigned to one of three groups, namely:

- Dyslexic – composed of dyslexic participants.
- CA controls – control participants matched with the dyslexic group for age and reasoning ability.
- SA controls – a second control group matched with the dyslexic group on spelling age and reasoning ability.

From a large pool of available participants who had been given the initial tests outlined in section 3.2.3, 90 participants were selected from 3 different schools, some of which took only dyslexic children and others that took dyslexics and other children. Each experimental group contained 30 participants that satisfied the criteria specified in section 3.2.4.

Stage 2

Participants were selected in such a way that they could be assigned to one of two groups, namely: dyslexics and controls matched in pairs for age and intelligence.

From a large pool of available participants who had been given the initial tests outlined in section 3.2.3, 60 new participants were selected from 7 schools, some of which took only dyslexic children and others that took dyslexics and other children. Each experimental group contained 30 participants that satisfied the criteria specified in section 3.2.4.

3.2.2 Age-bands for the Four Operations

Participants in the dyslexic and CA control groups were identified in three age bands as presented in Table 3.1. Participants from the SA matched control group are not represented here because of the very nature of their being matched with the dyslexics by spelling age which did not necessarily correspond with the age bands presented in Table 3.1.

Table 3.1 Chronological age range within each age band

Age Band	*Age (years and months)*
Young	9:5 – 11:4
Medium-age	11:5 – 13:4
Old	13:5 – 15:4

Throughout the research reference will be made to the three age bands: young, medium-age or medium age band and old based on the ages given in Table 3.1. In some places these terms are abbreviated to 'Y', 'M' and 'O'.

It was decided not to include any dyslexic participant under 9:5 years in the young age band because they would be most likely matched with a participant of approximately 7 years 1 month on spelling age. The SA controls would therefore have their chronological ages around their spelling ages, in line with the criteria of this research. Multiplication and division number facts may not be taught to children who are younger than 7 years old.

Each age band represents two years, spanning both the Junior and Senior stages of schooling. At the ages of 15/16 years students take important examinations (GCSE) to help determine their future career paths. This research was designed to examine the responses of students who were already participating in their GCSE coursework. Comparisons could then be made within age bands and also across them in the final analysis of results. By this means, the performance of the dyslexic participants could be accurately observed over a six-year age period.

Different participants were used in each age band. This was not a longitudinal study.

The control participants are sometimes referred to as non-dyslexics. Both terms are used interchangeably.

3.2.3 Testing

Preliminary tests were conducted in order to identify suitable participants for the research. All prospective participants undertook the following tests:

The Schonell S1 spelling test (Schonell and Schonell, 1952)

This test was straightforward to administer and was given to a large group simultaneously. The participant score on this test (number of words spelled correctly) was used to match participants across the experimental groups.

The Raven Standard Progressive Matrices (SPM) (Raven, 1958)

All the participants chosen were tested on reasoning power in order to forestall any possible objection that differences in the final results were due to this. In order to control for reasoning power Raven Matrices was chosen. In the case of those aged less than 8 years in the SA control group, the Raven Coloured Matrices (Raven, 1962) was used. Total raw scores were used to match participants across the experimental groups.

The Bangor Dyslexia Test (BDT) (Miles, 1982, 1997)

A test was required that could distinguish dyslexics from non-dyslexics. The BDT was chosen for two reasons: firstly for its scientific rigour, and secondly its clinical background.

> A recognisable pattern of difficulties was clearly emerging: in particular the spelling of many subjects seemed bizarre; many of them continued to confuse 'b' and 'd' at a relatively advanced age; and they were regularly showing some or all of the difficulties ... – problems over left-right, over repeating polysyllables, over subtraction and tables, and over repeating the months of the year and strings of digits. I was also confronted with clear evidence that the condition sometimes runs in families. Confirmation of these ideas came not only from discussions with colleagues and a study of the relevant literature, but from the fact that what I said was clearly making sense both to the children and to their parents. (Miles, 1993, p. 16)

In addition to any previous independent diagnosis, the researcher assessed each participant for any possible indication of dyslexia. The BDT was chosen in order make sure that none of the potential controls showed typical dyslexic behaviour, thus making sure that no dyslexic was included in the control group or vice versa.

When scoring the test, two sub-items, Subtraction and Tables, were excluded. This was in order to prevent inclusion of participants who had been selected because they were, in part, weak at the two sub-items that involved mathematics.

3.2.4 Criteria for Selection for the Four Operations

The following criteria were specified in the selection of participants.

No participant was included if they had:

(1) a gross physical handicap;

(2) major problems of adjustment;

(3) participants had to have a score on the Raven Standard Progressive Matrices (Raven, 1958) or on the Raven Coloured Matrices (Raven, 1962) that was above the 50th percentile for his age except in the case of one participant in the old CA control group whose score placed him on the 40th percentile. This was to ensure that the results were not affected by extraneous factors such as low reasoning ability.

Criteria for acceptance into the *dyslexic* group:

(1) a spelling age on the S1 spelling test (Schonell and Schonell, 1952) of not less than 18 months below chronological age, or 2 years below chronological age for participants over 13 years of age;
(2) at least 3.5 positive indicators out of 8 on the Bangor Dyslexia Test (Miles, 1982, 1997).

Criteria for acceptance into the *control* groups:

(1) a spelling age equal to or above chronological age or within 6 months of it, or in the case of children in the old age band, a spelling age of at least 12 years;
(2) not more than 2.5 positive indicators out of 8 on the Bangor Dyslexia Test.

To prevent any possible effects of gender difference it was decided to select only male participants.

3.2.5 Justification for Boundaries

The choice of the positive indicators on the Bangor Dyslexia Test was adjusted in line with this research concerning mathematics. Normally a score of 4 or more pluses on the Bangor Dyslexia Test gives an indication of dyslexia (Miles, 1982, 1997). In the Bangor Dyslexia Test there are two sub-tests connected to mathematics – Subtraction and Tables. If these two tests had been included in the selection process this could have attracted the legitimate criticism that a participant may have been chosen because of their poor scoring on the mathematical items of this test and thus the research results would have been biased by the selection procedure for participants. It was therefore decided not to include the results for 'Subtraction' and 'Tables' within the Bangor Dyslexia Test, leaving 8 instead of 10 sub-tests for scoring. A buffer zone on the Bangor Dyslexia Test was created so that there was a difference of at least one positive indicator between the dyslexic and non-dyslexic participants.

Setting the boundaries for spelling

Two participants in the young and medium-age dyslexic groups scored 18 months behind their chronological age on the spelling test. Both scored 51 and 55 respectively on the SPM and they gained at least 3.5 pluses on the BDT where both mathematical tests had been excluded. It was decided to set the spelling boundary for the young and medium-age dyslexics at 18 months behind chronological age as a result.

One participant in the old age band scored 72 on the spelling test making his spelling age 2 years behind his chronological age. He scored 56 on the SPM and on clinical grounds was obviously dyslexic, scoring at least 3.5 pluses on the BDT where the two mathematical items had been excluded. On this basis it was decided to set the spelling boundary at a maximum of 72 and at two years below chronological age for the old participants in the dyslexic group.

The gap between CA (mean chronological age of the participant during initial testing for selection as a suitable candidate) and *CA* (the mean chronological age during the mathematical testing) was sometimes as much as 20 weeks for practical reasons. It was therefore decided that, for valid comparisons to be made, the ages at which the calculation items were given should be the ones used. Thus it was considered appropriate to use the mean of the participant's age over the mathematical testing period.

The CA controls were matched with specific dyslexic partners on age, at time of mathematical testing, and intelligence (raw score). At most the CA control participant was no more than 2 months older than the dyslexic partner. At most the dyslexic was no more than 4 months older than his control partner. The overall mean age for the dyslexics in a group/age band was higher than the mean age for the CA controls.

In Stage 2 there were no cases where the CA controls were ahead of the dyslexics by more than 2 points on the SPM raw score. The overall mean raw scores were higher for the dyslexics in all age bands than the control groups.

Each participant thus experienced many preliminary series of tests before he was chosen for the main test in which his responses and answers would be recorded. Individual participant details for Stage 1 and Stage 2 are given in Appendix A (Tables A.1 to A.15)

3.2.6 Schools

All participants were chosen from seven private schools, two of which accepted only dyslexics and five of which had an established dyslexia unit. It was decided that these schools were sufficiently alike in socio-economic status and methods of teaching to justify the research selection criteria. Moreover, in the case of the dyslexic participants, their poor spelling performance could not be due to a lack of opportunity to learn.

This research was conducted in two stages with two different groups of participants. Stage 1 involved a study of performance on Multiplication and Stage 2 was concerned with experimentation on Division, Addition and Subtraction, thus rounding off a study of the four mathematical operations.

3.3 Stage 1 – The Multiplication Experiment

3.3.1 Participant Details

The mean chronological ages and spelling ages for the 9 groups are given in Table 3.2 and Table 3.3. Chronological ages and spelling ages are given in years and months, with standard deviations in months.

Table 3.2 Mean chronological ages, spelling ages, Raven Matrices quotient and Bangor Dyslexia Test pluses for the 3 groups and 3 age bands in Stage 1.

Group	*Type*	*Age Band*					
		Young		*Medium*		*Old*	
		Age or Matrices Score	*Standard deviation*	*Age or Matrices Score*	*Standard deviation*	*Age or Matrices Score*	*Standard deviation*
Dyslexics	CA	10:7	+/– 3.65	12:7	+/– 8.85	14:3	+/– 6.34
	SA	7:10	+/– 5.17	9:11	+/– 8.60	11:4	+/– 9.73
	MS	114	+/– 4.95	114	+/– 8.71	114	+/– 8.03
	BDT	7.3	+/– 1.58	5.8	+/– 1.40	5.8	+/– 1.44
	BDT*	5.75	+/– 1.34	4.85	+/– 1.08	4.7	+/– 1.16
CA controls	CA	10:0	+/– 4.24	12:1	+/– 8.11	14:1	+/– 5.52
	SA	10:11	+/– 7.49	12:11	+/– 5.55	13:11	+/– 4.23
	MS	113	+/– 6.08	112	+/– 7.62	110	+/– 4.32
	BDT	2.45	+/– 0.80	2.75	+/– 0.35	1.85	+/– 0.85
	BDT*	1.6	+/– 0.61	2.05	+/– 0.37	1.4	+/– 0.77
SA controls	CA	7:8	+/– 5.61	8:9	+/– 8.16	9:5	+/– 8.33
	SA	7:10	+/– 4.87	9:10	+/– 7.66	11:4	+/–10.23
	MS	111	+/–10.35	120	+/– 6.64	122	+/– 6.30
	BDT	2.75	+/– 0.82	1.7	+/– 1.09	1.75	+/– 1.03
	BDT*	1.6	+/– 0.97	1.1	+/– 0.77	1.1	+/– 0.91

Note.

CA = chronological age (years and months). Standard deviation is given in months.

SA = spelling age (years and months). Standard deviation is given in months.

MS = performance on Raven Standard Progressive Matrices or Raven Coloured Matrices.

BDT = Bangor Dyslexia Test.

BDT* = Bangor Dyslexia Test with Subtraction and Tables sub-items omitted.

Thus the dyslexics were marginally older than the CA controls and had marginally higher scores on the Raven Matrices. Any respect in which they performed worse than the CA controls could not therefore be the result of differences in age or reasoning powers.

Table 3.3 Mean chronological ages, spelling score, Raven Matrices score and Bangor Dyslexia Test pluses for the 3 groups and 3 age bands in Stage 1

Group	*Type*	*Age Band*					
		Young		*Medium*		*Old*	
		Age or Score	*Standard deviation*	*Age or Score*	*Standard deviation*	*Age or Score*	*Standard deviation*
Dyslexics	CA	127.3	+/– 3.65	151.2	+/– 8.85	171.3	+/– 6.34
	SS	27.6	+/– 5.17	48.8	+/– 8.60	63.3	+/– 9.73
	MS	42.3	+/– 3.16	47.0	+/– 4.03	49.6	+/– 3.47
	BDT	7.3	+/– 1.58	5.8	+/– 1.40	5.8	+/– 1.44
	BDT*	5.75	+/– 1.34	4.85	+/– 1.08	4.7	+/– 1.16
CA controls	CA	119.7	+/– 4.24	144.6	+/– 8.11	169.3	+/– 5.52
	SS	59.1	+/– 7.49	79.2	+/– 5.55	89.1	+/– 4.23
	MS	38.3	+/– 4.69	44.6	+/– 2.55	49.3	+/– 4.08
	BDT	2.45	+/– 0.80	2.75	+/– 0.35	1.85	+/– 0.85
	BDT*	1.6	+/– 0.61	2.05	+/– 0.37	1.4	+/– 0.77
SA controls	CA	91.8	+/– 5.61	105.2	+/– 8.16	112.5	+/– 8.33
	SS	27.8	+/– 4.87	48.2	+/– 7.66	63.2	+/–10.23
	MS	25.9	+/– 5.65	38.2	+/– 7.81	42.4	+/– 6.57
	BDT	2.75	+/– 0.82	1.7	+/– 1.09	1.75	+/– 1.03
	BDT*	1.6	+/– 0.97	1.1	+/– 0.77	1.1	+/– 0.91

Note.

CA = chronological age (months) with standard deviation in months.

SS = spelling score.

MS = raw score on the Raven Standard Progressive Matrices or Raven Coloured Matrices.

BDT = Bangor Dyslexia Test.

BDT* = Bangor Dyslexia Test with Subtraction and Tables sub-items omitted.

Up to a maximum of eight weeks elapsed between the time a participant was first asked to take part in a group administration of the Schonell S1 spelling test (Schonell and Schonell, 1952), through to the Raven Standard Progressive Matrices (1958) or Raven Coloured Matrices (1962) and individual observation in the Bangor Dyslexia Test (Miles, 1982, 1997).

3.4 Stage 2 – Division, Addition and Subtraction Experiments

3.4.1 Introduction and Participant Details

The Multiplication experiment gave rise to findings on correctness and speed of response. The results are discussed in Chapters 6 and 10. Further questions arose, regarding the dyslexics' performance on the other three operations in mathematics. Would the trend in the results of the Multiplication experiment be evident in addition, subtraction and/or division? See Chapter 16 for a comparison of the four operations.

Stage 2 preparations began after testing for Stage 1 was completed and the results analysed. Computer software was programmed with a similar format in mind but with a few modifications, which are outlined in this chapter.

Based on the findings for Stage 1 – Multiplication, the SA controls were not included in Stage 2. The overall results for the SA controls had indicated that their performance was both slower and less accurate than the dyslexic group in all age bands.

In Stage 2, division was to be tested and it was clear that in the school curriculum the subject of division would not be adequately covered until most pupils were in their ninth year of age. This linked in with the young age band in this research but by the very nature of matching on spelling age it was found that several participants would need to be sought who fell below this age in all the three potential spelling age groups. This was due to the low spelling scores of dyslexics in all age bands. An example of this can be seen in the old dyslexic group where one 15-year-old gained a spelling score which placed his spelling age in the six-year age bracket. To find and test a spelling age matched participant in his sixth year was not appropriate. On this basis it was decided to include CA controls and dyslexics in Stage 2 and exclude SA controls.

It was decided to question participants on one particular operation at a time instead of presenting a mixture of types of question (on division, addition and subtraction within the one experiment). Dyslexics are well known for confusing mathematical symbols.

Stage 2 group mean chronological ages, spelling ages and Raven Matrices quotients are given for each of the age bands in Table 3.4. Additionally, spelling scores and Raven Matrices scores are given in Table 3.5.

Table 3.4 Mean chronological ages, spelling ages, Raven Matrices quotient and Bangor Dyslexia Test pluses for the 2 groups and 3 age bands in Stage 2

Group	*Type*	*Age Band*					
		Young		*Medium*		*Old*	
		Age or IQ	*Standard deviation*	*Age or IQ*	*Standard deviation*	*Age or IQ*	*Standard deviation*
Dyslexics	CA	10:7	+/–7.80	12:3	+/– 4.50	14:9	+/— 4.31
	CA	10:8	+/– 7.47	12:5	+/– 5.46	14:10	+/—4.38
	SA	7:10	+/– 9.42	9:0	+/–10.54	10:7	+/–15.90
	MS	115	+/– 6.35	119	+/– 4.67	117	+/– 8.28
	BDT	6.95	+/– 1.59	6.3	+/– 1.46	5.75	+/– 0.98
	BDT*	5.15	+/– 1.38	4.95	+/– 1.09	4.55	+/– 0.76
Controls	CA	10:5	+/– 7.29	11:11	+/– 5.83	14:8	+/– 3.71
	CA	10:7	+/– 8.01	12:2	+/– 5.73	14:9	+/– 3.97
	SA	11:8	+/– 9.29	12:11	+/– 8.59	13:10	+/– 3.78
	MS	112	+/– 7.54	111	+/– 4.33	110	+/– 8.79
	BDT	2.05	+/– 0.90	1.8	+/– 0.86	2.45	+/– 0.50
	BDT*	1.45	+/– 0.86	1.1	+/– 0.61	1.9	+/– 0.66

<u>Note.</u>

CA = chronological age (years and months).

CA = mean age of the participants when performing the mathematical experiments.
SA = spelling age (years and months).
MS = performance quotient on Raven Standard Progressive Matrices or Raven Coloured Matrices.
BDT = Bangor Dyslexia Test.
BDT* = Bangor Dyslexia Test with Subtraction and Tables sub-items omitted.
In the case of CA, *CA* and SA the standard deviation is given in months.

In each age band the dyslexic group chronological mean age is therefore higher than the controls and their mean scores are higher on the test of reasoning power.

Table 3.5 Mean chronological ages, spelling scores, Raven Matrices scores and Bangor Dyslexia Test pluses for the 2 groups and 3 age bands in Stage 2.

Group	*Type*	*Age Band*					
		Young		*Medium*		*Old*	
		Age or Score	*Standard deviation*	*Age or Score*	*Standard deviation*	*Age or Score*	*Standard deviation*
Dyslexics	CA	126.7	+/– 7.80	147.3	+/– 4.50	177.1	+/– 4.31
	CA	128.3	+/– 7.47	148.6	+/– 5.46	178.1	+/– 4.38
	SS	28.4	+/– 9.42	40.4	+/–10.54	56.0	+/–15.90
	MS	42.4	+/– 6.04	49.4	+/– 2.55	51.2	+/– 3.88
	BDT*	5.15	+/– 1.38	4.95	+/– 1.09	4.55	+/– 0.76
Controls	CA	124.7	+/– 7.29	143.3	+/– 5.83	176.2	+/– 3.71
	CA	127.1	+/– 8.01	146	+/– 5.73	177.3	+/– 3.97
	SS	66.9	+/– 9.29	79.4	+/– 8.59	87.6	+/– 3.78
	MS	39.7	+/– 4.32	44.5	+/– 2.55	48.1	+/– 4.07
	BDT*	1.45	+/ 0.86	1.1	+/– 0.61	1.9	+/– 0.66

Note.

CA = chronological age (months).
CA = mean age of the participants when performing the mathematical experiments.
SS = spelling score.

MS = raw score on the Raven Standard Progressive Matrices or Raven Coloured Matrices.

BDT* = Bangor Dyslexia Test with Subtraction and Tables sub-items omitted.

In the case of CA and *CA* the standard deviation is given in months.

3.5 Apparatus

The apparatus section of this chapter is subdivided into the two main experimental stages presented in 3.6 and 3.7 and the apparatus used is detailed.

3.6 Stage 1 – Apparatus for the Multiplication Experiment

3.6.1 Introduction

After selection in accordance with the criteria outlined above, each participant was given instruction in the use of an Amstrad PPC 640D portable computer with a white on black Sinclair S-12 MM screen placed centrally in front of him. The screen was positioned so that any glare from lighting or sunlight was minimised. The Amstrad keyboard was so placed as to position the participant centrally to the number board located on the right of the keyboard.

3.6.2 Software Design

The following disks were used:

(1) Microsoft MSDOS operating system
(2) program working disk
(3) storage disks
(4) Lotus 123
(5) WordStar Express
(6) SPSS Software Package

3.6.3 The Program Working Disk

This disk was created with the following format:

(1) A set presentation of 10 multiplication questions presented centrally, one at a time on the monitor, in the following sequence:

$1 \times 1, 1 \times 2, 1 \times 3, 1 \times 4, 1 \times 5, 1 \times 6, 1 \times 7, 1 \times 8, 1 \times 9, 1 \times 10$

The answers indicated by the participant would enable him to become familiar with the position and operation of all the keys.

(2) 10 random (pre-set) multiplication questions presented individually on the screen as a preliminary practice in the following sequence:

$3 \times 4, 5 \times 10, 6 \times 2, 1 \times 12, 5 \times 3, 7 \times 5, 10 \times 10, 8 \times 4, 11 \times 9, 12 \times 2$

(3) The main test of 144 random (pre-set) multiplication questions presented individually on the screen. Tables of Random Permutation (Moses and Oakford, 1963) were used to select at random the order of the questions, using the 144-squared multiplication grid as a preparation pad.

As an example, the number 76 is given as the first number on page 141 of Table 7 (Moses and Oakford, 1963), so this was transposed to box 76 on a pre-numbered multiplication grid. The grid was so numbered as to start with 1×1 as box 1, following on in sequence horizontally to 12×1 as box 12. The maximum number of boxes was 144. Where Table 7, followed sequentially, showed a number greater than 144, this was discarded. Because box 76 was the first to be selected from the random numbers presented in Table 7 this was found to correspond to 4×7 (taking the horizontal reading first) and hence this was to become the first question for all participants in Trial 1 as part of the main experiment. A second trial was prepared whereby all the questions were rotated around a central point so that the first question 4×7 in Trial 1 became the last question; the second question in Trial 1 became the second to last question in Trial 2 and so on.

(4) A maximum presentation time of 22 seconds – from the pilot study it was established that 99.8% of responses, whether accurate or inaccurate, were made within the range of 0–20 seconds. Accordingly, it was decided to adopt a 20-second upper limit with a 10% tolerance margin. This produced a time of 22 seconds as the maximum permitted time for a response by any of the participants in the research.

The alternative was to adopt an arbitrary time limit, determined a priori, such as 60 seconds. This would have created a potentially unmanageable set of testing procedures that could have lasted for over two hours for any participant in the worst-case scenario.

The data produced, it is contended, reveals a very small percentage error. This error would be a Type II error in that it would create false negatives that would reduce the probability of finding significant differences or factors in the research.

This conservative approach has been adopted throughout the research and, as such, may explain a small number of cases where a significant difference has failed to be substantiated. This was felt to be the less damaging alternative of the two options, as it is empirically based and, if anything, biases the research towards the null hypothesis.

The disk was created using Turbo Basic, with the help of a computer programmer/analyst. The programmer analysed the program development to achieve the objectives. The algorithm was written and subsequently coded, debugged and modified as requirements were refined.

3.7 Stage 2 – Apparatus for the Division, Addition and Subtraction Experiments

3.7.1 The Computer and Base

Each participant was given instruction in the use of an AST Bravo NB 4/25s Laptop Computer with an attached numeric keypad. The numeric keypad became integral with the computer by placing it on a specially designed base that centrally located the device to enable quick assembly and consistent location close to and in front of the screen. The base was placed over the Laptop keyboard to prevent the participants from selecting irrelevant keys. The base was padded to help with comfort of prolonged use.

3.7.2 The Numeric Keypad

This pad comprised the numbers 0 through to 9 with a large "Enter" key laid out in the regular figuration presented on the right-hand side of a full computer keyboard. Other keys on the keypad, which were unnecessary for this research, were covered over to prevent visual distraction and mistaken use. Additional precautions were taken by disconnecting the "Delete" key, as it lay very close to the "Enter" key – it was felt necessary to do this because under timed conditions a participant wishing to operate quickly may inadvertently 'catch' this key.

3.7.3 Software Design

The following disks were used:

(1) WordPerfect word processor package.

(2) React and Program disks, written in Turbo Basic (aided by X Tree Pro) by a computer programmer, were loaded on the hard drive for immediate boot up.

(3) Storage of data was automatic onto the hard disk under the heading 'Data Storage'.

(4) SPSS statistical analysis program.

(5) Presentation of statistical data on Microsoft Word and Microsoft Excel.

3.7.4 Program Working Disc

This was designed in the same way as for Stage 1. Pre-tests were included for each operation in Stage 2; these were the set pre-test and then a random pre-test, like Stage 1. The main test consisted of 150 questions (Addition and Subtraction experiment) and 144 questions for the Division experiment, presented individually on the screen. The order of the questions was decided in the same way as for Stage 1 – Tables of Random Permutation (Moses and Oakford, 1963) were used to select at random, the order of the questions.

3.7.5 Program Working Disk – Improvements

As a result of the practical experience gained from Stage 1, improvements were made to the new program for ease of use and analytical measurement. The improvements comprised:

(1) An auditory single 'beep' to signal the appearance of the next question. This was included for the purpose of focusing the participant's mind on the start of the next question.

(2) The screen presentation was changed from black to white to alert the participant to the imminent change of question. This coincided with the beep. Thus a multi-sensory visual and auditory primer was given to participants on each question.

(3) It was decided to enlarge the number screen presentation to a digit height of 1.5 cm for greater clarity. The digits were positioned centrally from left to right but 4 cm down from the top of the screen and 9 cm up from the bottom of the screen in order to cater for the Base and Numeric Keypad location. The screen width was 19.25 cm and the screen height was 14.5 cm. The digits were therefore presented (taking their base) 5.5 cm from the top of the screen. There was a 0.5 cm gap between digits where 2 digits were included in a number.

(4) No changes were made to the interval between question presentations, the maximum 22 second presentation or the halfway point in the main experiment.

(5) Measurement considerations: as a result of using a more powerful computer, greater analysis of data was possible. Each time the participant depressed a key, the computer timed this response, thus enabling measurements between:

(a) screen question display and first key; first key and "Enter" response;

(b) screen question display and first key; between first key and second key; between second key and "Enter" response;

(c) screen question display and first key; between first key and second key; between second key and third key; between third key and "Enter" response where applicable;

(d) the total response time between screen question display and "Enter";

(e) screen question display to no response within 22 seconds (called a 'miss');

(f) screen question display to "Enter" where not enough keys were pressed for the correct answer (called a 'pass').

The next four sections (3.8 to 3.11) detail the methodology for each of the four operations.

3.8 The Multiplication Experiment

3.8.1 Instructions for Program Working Disk (Main Instructions)

With the participant comfortably positioned in front of the computer, the experimenter keyed in the preliminary details of name and age in years and months for accurate identification later. The participant was instructed as follows:

(1) 'You will be working on the computer which will be timing how quickly you respond.'

(2) 'The computer will ask you questions on the screen here [experimenter indicates the centre of the screen] and you then press the answer in here [experimenter indicates the numeric keypad]. Once you have pressed your answer, you must press the "Enter" key immediately because you are still being timed. It is called 'enter' because you want to enter your answer into the computer's memory.'

(3) 'The clock inside the computer will start timing you from the moment the question appears on the screen. It stops timing you as soon as you press the "Enter" key.'

(4) 'Think of the answer as quickly as possible and always have your hand or hands at the ready.'

(5) 'If you really don't know the answer, press the "Enter" key alone. That question will disappear and the computer will ask you the next question, so be ready for it. We would like you to answer as many of the questions as possible for this research.'

(6) 'After a reasonable length of time, if you have not answered a question, it will disappear – so keep your eyes on the screen so that you don't miss the next question.'

At this point the experimenter sequentially showed the participant each number on the pad, naming each one as it was pointed out.

(7) 'The "Delete" key does not work. If you make a mistake call out your answer and I will make a note of it.'

(8) 'When I say Ready, Steady, Go, press the "Enter" key to start.'

The experimenter now exchanged places with the participant, who then took his seat in front of the screen and numeric keypad, and the testing began.

For all four operations the question remained on the screen, while the participant typed in his response (this was shown on the computer screen), until the participant pressed the "Enter" key or "Missed" if 22 seconds had elapsed.

3.8.2 Set Pre-test

The participant was asked the ten questions in ascending order so that he could familiarise himself with the positions of the numbers on the keys. This pre-test also allowed the participant time to consider which hand or hands he was going to use before the main test began. The participant could use this opportunity to develop an understanding of the way in which he needed to press the keys so that his answers would appear on the screen.

The 10 multiplication questions were presented one at a time on the monitor, in the following sequence:

$$1 \times 1, 1 \times 2, 1 \times 3, 1 \times 4, 1 \times 5, 1 \times 6, 1 \times 7, 1 \times 8, 1 \times 9, 1 \times 10$$

The answers indicated by the participant would enable him to become familiar with the position and operation of all the keys.

On completion of this pre-test the following instruction was displayed on the screen:

> Question ONE will start when you press "ENTER".

3.8.3 Random Pre-test

This pre-test enabled the participant to become familiar with the kind of variation that he was about to encounter in the main experiment. These ten questions were specifically asked because they included all the numbers from 1 to 12.

The 10 random (pre-set) multiplication questions were presented individually on the screen as a preliminary practice in the following sequence:

$$3 \times 4, 5 \times 10, 6 \times 2, 1 \times 12, 5 \times 3, 7 \times 5, 10 \times 10, 8 \times 4, 11 \times 9, 12 \times 2$$

On completion of this pre-test the following instructions were displayed on the screen:

> You have completed the short section [This was visible for only one second before the next instruction was given below.]
>
> Question ONE will start when you press "ENTER".

3.8.4 Main Experiment – Multiplication

The main test of 144 random (pre-set) multiplication questions were presented individually on the screen. See section 3.6.3 for details on how the order of questions was chosen.

3.8.5 Question Order for Multiplication

The questions and the order in which they were presented are in Appendix B (Table B.1).

The first 72 questions were displayed on the screen, one at a time, and the participant responded in accordance with his instructions. This was followed by an interval of a few minutes. The interval was followed by questions 73 to 144. On reaching question 144, the participant had completed Trial 1.

Trial 2 then took place during the following two weeks. The same procedure, including the two pre-tests, was carried out to familiarise the participant with the task in hand. This time in the Main Experiment, the questions were pivoted around a central point, as explained in section 3.6.3.

The researcher carried out all the testing for this research, seated either to the side of the participant some four feet away, or slightly behind the participant at the same distance. This was in order to establish a situation in which the participant would not be too self-conscious or even be aware that he was under observation, which could have had an adverse effect upon his concentration and responses. It was also necessary for the researcher to see the screen. She therefore sat in an unobtrusive position, but within sight of the computer.

At the end of each testing session the participants were thanked for their help but no comments were made on their performance.

3.8.6 Recording Components by the Computer

The computer had been programmed to store the following data:

(1) The question asked, the correct answer, the answer given and the time taken for each individual key to be pressed in response, as well as a total response time to the nearest one hundredth of a second.

(2) A total breakdown of the four different types of response, namely right answers, wrong answers, passed questions and missed questions for the two pre-tests and the two halves of the Main Experiment.

All the data were stored in ASCII format, which was 'comma delimited' as a preparation for analysis by the SPSS software package.

3.8.7 Response Categories for Analysis

(1) *Correct* – where a participant answered correctly within the 22-second time-limit available the response was counted as 'correct'.

(2) *Incorrect* – where a participant responded within the 22-second time-limit available but typed in the wrong answer prior to pressing "Enter".

(3) *Missed* – where a participant did not press "Enter" before the 22-second time-limit. The participant may or may not have supplied an answer.

(4) *Passed* – where a participant decided that they were unable to answer a question, they were able to press "Enter" and move directly on to the next question. The time taken to make this decision was recorded.

Results for this experiment are given in Chapter 6 (Correctness) and Chapter 10 (Speed). The researcher explored the number of individual observations where young dyslexics in particular realised that they didn't have any prospect of giving an answer to a multiplication question. They tended to pass relatively quickly after stimulus presentation whereas for all other groups this tendency was not so pronounced. Accordingly two measures of central location were used – a median value for each of the group age bands and a compensated mean time, where all inaccurate responses were coded at the maximum time out level of 22 seconds.

Where a particular multiplication table has been referred to in the results, a multiplication sign has been placed after the table number, e.g. $2\times$, meaning in this case the two times multiplication table.

3.9 The Division Experiment

As with the Multiplication experiment, Division shared many similarities, namely:

(1) The use of the same combinations of numbers ranging from $1 \div 1$ through to $144 \div 12$. All possible division questions between this range were used.

(2) Only division questions resulting in whole number answers with no remainders were used.

(3) The method of random selection for the order of the questions was the same.

(4) The same number of questions (144) with an interval at the halfway point was used.

The concept of division shares a similar foundation to that found in multiplication. The two operations are interchangeable, for example, $5 \times 7 = 35$ and $35 \div 7 = 5$.

3.9.1 Instructions for Program Working Disk (Main Instructions)

The experimenter keyed in the preliminary details of participant name, age and school, for accurate identification later. In addition the experimenter made a note of these details in a separate notebook together with participant's date of birth and date of testing. Each participant had a page entry ready for observations.

The experimenter then explained the details of the test situation and gave the following instructions to the participant:

(1) 'You will be working on the computer that will be timing how quickly you respond to questions on division.'

(2) 'The computer will ask you a question on the screen here [experimenter indicates the centre of the screen where the characters will appear] and you then press the answer in here [experimenter indicates the numeric keypad].'

(3) 'Once you have pressed in your answer, you must then press the "Enter" key [experimenter points this out] immediately to stop the clock. You are being timed from the moment the question appears on the screen to the time when you type in your answer and press the "Enter" key.'

(4) 'If you really don't know the answer and can't work it out, you may press the "Enter" key by itself to make that question go away. The next question will then come up. This will be signalled by a beep to let you know it is there.'

(5) 'There is a maximum time period of about 20 seconds to answer a question. If you take longer than this, the question will go away and the next question will appear.'

At this point the experimenter sequentially showed the participant each number on the numeric keypad from 0 through to 9, naming each one as it was pointed out. The "Enter" key was clearly indicated and named again.

(6) 'The "Delete" key has been instructed not to work. If you make a mistake, hard luck, there is nothing we can do. You then move on to the next question by pressing the "Enter" key.'

(7) 'Like a football match there are two short warm up sessions, and then two halves with an interval in the middle. We will take a short break when you get to the interval.'

(8) 'Remember that you are being timed so think of the answer as quickly as you can.'

The participant then had an opportunity to clarify any part of the instructions and then changed places with the experimenter in order to begin. The experiment was initiated by pressing the "Enter" key once.

3.9.2. Set Pre-test

The Set pre-test was designed to encourage sequentially increasing responses from the participant so that he was able to become familiar with the type of division questions and experience pressing different numbers on the numeric keypad. Nine questions were prepared designed to evoke responses ranging from 1 through to 9 on the numeric keypad.

The question order was:

$$1 \div 1, 2 \div 1, 3 \div 1, 4 \div 1, 5 \div 1, 6 \div 1, 7 \div 1, 8 \div 1, 9 \div 1$$

On completion of this pre-test the following instruction was displayed on the screen:

> Question ONE will start when you press "ENTER".

3.9.3 Random Pre-test

This was a preliminary test of ten questions designed to prepare the participant for the type and range of questions in the main Division experiment. Both questions and answers employed the use of all the division tables (except 8 and 11 due to there being ten questions and 12 division tables) and all of the keys on the numeric keypad (except 8 and 0). These ten questions were repeated at differing points in the Main Experiment.

No question in this experiment involved the use of '0', either in the numerator or denominator, since this would have increased the number of questions beyond a reasonable length. The inclusion of '0' would have added an unwanted variable.

The question order was:

$$8 \div 4, 22 \div 2, 42 \div 7, 5 \div 5, 70 \div 10, 4 \div 1, 81 \div 9, 72 \div 6, 36 \div 12, 15 \div 3$$

On completion of this pre-test the following instructions were displayed on the screen:

> You have completed the short section. [This was visible for only one second before the next instruction was given below.]
>
> Question ONE will start when you press "ENTER".

3.9.4 Main Experiment – Division

The participants needed to press the "Enter" key to signal the start of the Main Experiment. They had been exposed to both pre-tests and had therefore been prepared for the type of questions to come. A total of 144 division questions were presented in random order chosen in the same manner as that for multiplication. After 72 questions the participant reached an interval. On pressing the "Enter" key twice, the second half of the experiment was activated and the remaining questions were displayed one at a time.

Research from Stage 1 showed that the difference in performance from Trial 1 and Trial 2 in the Multiplication experiment was minimal. Statistically the mid-point was taken between the two multiplication trials but was not significant. Due to these results and the fact that each participant was performing on the Addition, Subtraction and Division trials as part of Stage 2, it was felt by the experimenter that each participant had been researched to the appropriate degree. Therefore only one trial was performed for the Division experiment.

3.9.5 Question Order for Division

The questions and the order in which they were presented are in Appendix C (Table C.1).

The participants performed the three experiments (Division, Addition and Subtraction) on different days in order to approach each experiment afresh. The time lapse between experiments ranged from the next day to four weeks.

At the end of each testing session the participants were thanked for their help but no comments were made on their performance.

3.9.6 Recording Components by the Computer

These are the same as for the Multiplication experiment (see section 3.8.6).

3.9.7 Response Categories for Analysis

These are the same as for the Multiplication experiment (see section 3.8.7).

Results for this experiment are given in Chapter 7 (Correctness) and Chapter 11 (Speed).

3.10 The Addition Experiment

3.10.1 Instructions for Program Working Disk (Main Instructions)

The instructions given were the same as those for the Division experiment with the word 'addition' substituted for 'division'.

The participant then had an opportunity to clarify any part of the instructions and then changed places with the experimenter in order to begin. The experiment was initiated by pressing the "Enter" key once.

3.10.2 Set Pre-test

The participant was asked nine questions in ascending order so that he could familiarise himself with the positions of the numbers on the keys. This also allowed the participant the opportunity of finding the most comfortable hand/s to use for responding prior to the Main Experiment. The participant could also become familiar with the presentation and response pattern required.

The addition questions were as follows:

$$1 + 0, 1 + 1, 1 + 2, 1 + 3, 1 + 4, 1 + 5, 1 + 6, 1 + 7, 1 + 8$$

When answering these questions, the participant responded by pressing each number key in sequential order. The nuances of the experimental situation also became apparent to the participant.

On completion of this pre-test the following instruction was displayed on the screen:

> Question ONE will start when you press "ENTER".

3.10.3 Random Pre-test

This pre-test enabled the participant to become familiar with the kind of variation that he was about to encounter in the Main Experiment.

Ten questions were asked in the following order:

$$24 + 2, 53 + 8, 69 + 4, 37 + 26, 71 + 7, 28 + 6, 61 + 8, 35 + 57, 21 + 3, 89 + 2$$

This selection included two questions from each of the five different categories of addition (explained in the Main Experiment), arranged in random order. All of these questions were novel and were not duplicated in the Main Experiment.

On completion of this pre-test the following instructions were displayed on the screen:

> You have completed the short section. [This was visible for only one second before the next instruction was given below.]
>
> Question ONE will start when you press "ENTER".

3.10.4 Main Experiment – Five Categories

The Main Experiment comprised 75 addition questions falling into *five equal categories*. The rationale for the five categories was such that the range of possible addition questions that could have been used was vast. It was decided to study the effect of two main factors: the addition of low compared to high addends, and secondly crossing and not crossing the ten barrier. The ten barrier refers to a change from one group of tens to another, e.g. 19 + 4 = 23, where the original number 19 has one group of ten and the sum of 19 + 4 gives 23 which has two groups of ten. An addition question such as 23 + 4 does not cross the ten barrier since the resulting sum 27 still retains the same number of tens (namely 2).

Would the size of the addend and/or addition across the ten barrier or within a grouping of ten have a larger effect on dyslexics compared to controls?

Category 1 (for Addition)

This comprised the addition of a low addend (2, 3, 4) to a two-digit number where the sum did not cross the ten barrier. It was labelled LN, an acronym for 'Low addend Not crossing the ten barrier'. Two examples from LN are: 47 + 2 and 64 + 3.

There were 15 questions in this category and each low addend was used five times. The choice of questions in this category was shaped by the constraints that the number system imposed, namely: in the two-digit number the distribution of the 'tens' ranged from the 20s to the 90s and the distribution of the 'units' ranged from 1 to 7.

Category 2 (for Addition)

This category included the addition of high addends (6, 7, 8) to two-digit numbers where the resultant sum did not cross the ten barrier. It was labelled HN, which stands for 'High addend Not crossing the ten barrier'. Two examples from HN are: 92 + 6 and 41 + 8. There were 15 questions in this category and each high addend was used five times.

The choice of questions in this category was shaped by the constraints that the number system imposed, namely: in the two-digit number the distribution of the 'tens' ranged from the 20s to the 90s and the distribution of the 'units' ranged from 1 to 3. The resulting answers had an 8 or 9 in the 'unit' position.

Category 3 (for Addition)

This group contained 15 questions chosen with low addends (2, 3, 4) added to two-digit numbers with the resulting sum crossing the ten barrier. It was labelled LC, which stands for 'Low addend Crossing the ten barrier'. Two examples from LC are: 29 + 2 and 47 + 4. There were 15 questions in this category and each low addend was used five times.

The choice of questions in this category was shaped by the constraints that the number system imposed, namely: in the two-digit number the distribution of the 'tens' ranged from the 20s to the 80s and the distribution of the 'units' ranged from 7 to 9. The resulting answers had a 1, 2 or 3 in the 'unit' position.

Category 4 (for Addition)

This category included two-digit numbers with high addends (6, 7, 8) and sums which crossed the ten barrier. It was labelled HC, which stands for 'High addend Crossing the ten barrier'. Two examples from HC are: 37 + 6 and 73 + 8. There were 15 questions in this category and each high addend was used five times.

The choice of questions in this category was shaped by the constraints that the number system imposed, namely: in the two-digit number the distribution of the 'tens' ranged from the 20s to the 80s and the distribution of the 'units' ranged from 3 to 9.

Category 5 (for Addition)

This additional category was chosen to represent the hardest questions of all. Their components included the addition of a two-digit number to another two-digit number where the addend units were high (6, 7, 8) and the resulting sums crossed the ten barrier with 'carrying'. It was labelled as the HARD category and two examples are as follows: 65 + 26 and 35 + 28.

The choice of questions in this category was shaped by the constraints that the number system imposed, namely: in the first two-digit number the distribution of the 'tens' ranged from the 20s to the 60s and the distribution of the 'units' ranged from 3 to 9. The addends included numbers ranging from the 20s to the 60s with the distribution of the 'units' ranging from 6 to 8.

Addition questions within each category are given in Appendix D (Table D.1).

3.10.5 Decisions about the Questions

Careful consideration was given to the digits used in the Addition experiment. The experiment did not sample the whole population of addition sums but only a specified selection so as to avoid increasing the variables. A decision was made to restrict the design to certain types of question otherwise the number of sums needed would have been too great. High (large) and low (small) addends were selected as well as sums that crossed and did not cross the ten barrier because they seemed interesting; as a logical consequence, certain other sums were therefore excluded.

Decisions were made to exclude the following:

(1) *Zeros in both the questions and answers.* The ten barrier is the point at which there is a change in the value of the number in the tens position. This point is also indicated by a zero in the units position. Questions were sought which actually involved the 'crossing' of the ten barrier. Additionally a question with a zero in it could, by its very nature, only be included in LN and HC categories, and this would give an unfair advantage to these categories in terms of correctness and speed. In the light of comparisons between categories, it was decided not to include zero as an added variable. Addition of an addend to a zero in the units position is much easier than considering the answer to a question which has numbers greater than zero in the units position.

(2) *Doubletons in both the questions and answers*, such as 33 or 55. These are visually eye catching and, as such, would have added another variable to the experiment. A doubleton can be typed in more quickly than two differing numbers as an answer. Doubletons were not included in the Key Search Reaction Time Test (see section 4.4).

(3) *Teen numbers* such as 14. When verbalising a teen number that the units number is 'said' first could cause confusion, especially for dyslexic participants when they are searching for the numbered keys to press in their answer.

(4) *Similar numbers in the tens or units* such as 53 + 3 or 26 + 27. These become easier if there is prior knowledge of the 2 times table. Moreover, this is an addition rather than a multiplication experiment.

(5) *Answers over 99*, thus eliminating any answer equal to or over 100. This decision limited the answer to two digits thereby avoiding the added complication of the 'hundred barrier'.

3.10.6 Question Order for Addition

Each question was assigned a number from 1 to 75. These numbers were placed individually in a hat and numbers were pulled out at random. Checks were made to see if there were any repetition of digits in the corresponding question in relation to the previous question, discarding such cases and returning the number back into the hat. Where an answer required was the same as a preceding question, that too was discarded.

The order of the questions is given in Appendix D (Table D.2).

Participants then reached the interval, which was of a variable length of time.

To continue with the second half of the Addition experiment, the participant needed to press the "Enter" key twice. This began Trial 2 in the one sitting, whereby all the questions were repeated but in reverse order. Thus the first question asked was '64 + 3 =' following through sequentially to the final question which was '21 + 7 ='.

At the end of each testing session the participants were thanked for their help but no comments were made on their performance.

3.10.7 Recording Components by the Computer

These are the same as for the Multiplication experiment (see section 3.8.6).

3.10.8 Response Categories for Analysis

These are the same as for the Multiplication experiment (see section 3.8.7).

Results for this experiment are given in Chapter 8 (Correctness) and Chapter 12 (Speed).

3.11 The Subtraction Experiment

3.11.1 Instructions for Program Working Disk (Main Instructions)

The instructions for the Subtraction experiment took the same form as for the Division experiment but the word 'subtraction' was substituted for 'division'.

3.11.2 Set Pre-test

As with addition this pre-test comprised 9 questions designed to evoke a response in ascending order of digits on the numeric keypad. The questions were as follows:

$$10-9,\ 10-8,\ 10-7,\ 10-6,\ 10-5,\ 10-4,\ 10-3,\ 10-2,\ 10-1$$

On completion of this pre-test the following instruction was displayed on the screen:

Question ONE will start when you press "ENTER".

3.11.3 Random Pre-test

This test contained two questions from each of the five subtraction categories, outlined later. None of the questions would be duplicated in the Main Experiment.

Ten questions were asked in the following order:

$$27-2,\ 64-8,\ 81-3,\ 73-36,\ 41-7,\ 96-4,\ 79-6,\ 84-28,\ 58-7,\ 32-4$$

On completion of this pre-test the following instructions were displayed on the screen:

> You have completed the short section. [This was visible for only one second before the next instruction was given below.]
>
> Question ONE will start when you press "ENTER".

3.11.4 Main Experiment — Five Categories

As for the Addition experiment, *five categories* were arranged to follow the same pattern of questioning. The term 'subtrahend' is used for the number being subtracted.

Category 1 (for Subtraction)

This comprised low numbers (2, 3, 4) subtracted from two-digit numbers. The resulting answer did not cross the 'ten' barrier. It was labelled LN, which stands for '<u>L</u>ow subtrahend <u>N</u>ot crossing the ten barrier'. Two examples of the LN category are: 29 – 2 and 67 – 4.

There were 15 questions in this category and each low subtrahend was used five times.

Category 2 (for Subtraction)

This comprised high numbers (6, 7, 8) subtracted from two-digit numbers. The resultant answer did not cross the 'ten' barrier. It was labelled HN, which stands for '<u>H</u>igh subtrahend <u>N</u>ot crossing the ten barrier'. Two examples of the HN category are: 87 – 6 and 58 – 6.

There were 15 questions in this category and each high subtrahend was used five times.

As a consequence of the design, all the answers include 1, 2 or 3 in their 'units'.

Category 3 (for Subtraction)

This comprised low numbers (2, 3, 4) subtracted from two-digit numbers and the resulting answer crossed the 'ten' barrier. It was labelled LC, which stands for 'Low subtrahend Crossing the ten barrier'. Two examples of the LC category are: 31 – 2 and 82 – 4.

There were 15 questions in this category and each low subtrahend was used five times.

Category 4 (for Subtraction)

This comprised high numbers (6, 7, 8) subtracted from two-digit numbers and the resulting answer crossed the 'ten' barrier. It was labelled HC, which stands for 'High subtrahend Crossing the ten barrier'. Two examples of the HC category are: 95 – 6 and 67 – 8.

There were 15 questions in this category and each high subtrahend was used five times.

Category 5 (for Subtraction)

This comprised two-digit numbers with high 'unit ' subtrahends of 6, 7 or 8 subtracted from two-digit numbers with the resultant answer crossing the 'ten' barrier with a 'borrowing' effect. It was labelled HARD, which stands for 'High subtrahend in the hard category'. Two examples of the HARD category are: 51 – 26 and 86 - 37.

There were 15 questions in this category and each high subtrahend was used five times.

Subtraction questions within each category are given in Appendix E (Table E.1).

3.11.5 Decisions about the Questions

Careful consideration was given to the digits used in the Subtraction experiment as in the Addition experiment. The experiment did not sample the whole population of subtraction sums and a decision was made to restrict the design to certain types of question otherwise the number of sums needed would have been too great. High (large) and low (small) subtrahends were selected as well as sums that crossed and did not cross the ten barrier because they seemed interesting; as a logical consequence, certain other sums were therefore excluded.

Decisions were made to exclude the following:

(1) *Any subtraction answer under ten* – this prevented one-digit answers. All answers were two digits for the purposes of comparison.

(2) *Subtraction of ten from any number.*

(3) *Negative numbers* – all answers were positive.

(4) *Taking away of doubles*, such as 80 – 40 or 16 – 8.

(5) *Taking away within a multiplication table*, for example 18 – 6 where 6 is a factor of 18.

(6) *Subtracting 0.* This has been avoided across all the experiments.

(7) *Subtraction of 'similars'*, such as 8 – 8.

Participants attended for this experiment and the Addition experiment on separate days so as to eliminate fatigue or confusion between the operations.

3.11.6 Question Order for Subtraction

A total of 75 questions were presented to the participant, which included a mixture of the five categories outlined above. The order of the questions was chosen as for the Addition experiment and the format was the same. See Appendix E (Table E.2) for the order of questions given in the Subtraction experiment.

Participants then reached the interval, which was of a variable length of time.

To continue with the second half of the Subtraction experiment, the participant needed to press the "Enter" key twice. This began Trial 2 in the one sitting, whereby all the questions were repeated but in reverse order. Thus the first question asked was '51 – 26 =' following through sequentially to the final question which was '52 – 7 ='.

At the end of each testing session the participants were thanked for their help but no comments were made on their performance.

3.11.7 Recording Components by the Computer

These are the same as for the Multiplication experiment (see section 3.8.6).

3.11.8 Response Categories for Analysis

These are the same as for the Multiplication experiment (see section 3.8.7).

Results for this experiment are given in Chapter 9 (Correctness) and Chapter 13 (Speed).

3.12 Statistical Tests

The following statistical tests have been conducted on the data.

3.12.1 Two-way Analysis of Variance

This test enables more than two samples to be studied simultaneously where differences between the means are compared. Variance is analysed within groups and between groups.

Once it has been established that differences exist among the means, post hoc range tests and pairwise multiple comparisons can determine which means differ. Range tests identify homogeneous subsets of means that are not different from each other. Pairwise multiple comparisons test the difference between each pair of means, and yield a matrix where asterisks indicate significantly different group means at an alpha level of 0.05.

Tamhane's T2 test of differences is a multiple comparison test that does not assume equal variances.

3.12.2 General Linear Model (GLM) for Analysis of Variance

These are post hoc multiple comparison tests. Once it has been determined that differences exist among the means, post hoc range tests and pairwise multiple comparisons can determine which means differ. Comparisons are made on unadjusted values. These tests are used for fixed between-subjects factors only. In GLM Repeated Measures, these tests are not available if there are no between-subjects factors, and the post hoc multiple comparison tests are performed for the average across the levels of the within-subjects factors. For GLM Multivariate, the post hoc tests are performed for each dependent variable separately.

Tamhane's T2 test of differences is used when the variances are unequal (conservative pairwise comparisons test based on a t-Test).

The least significant difference (LSD) pairwise multiple comparison test is equivalent to multiple individual t-Tests between all pairs of groups. The disadvantage of this test is that no attempt is made to adjust the observed significance level for multiple comparisons.

3.12.3 Kolmogorov-Smirnov Z Test

This tests if two independent samples have been drawn from populations with the same distribution. Two-tailed tests are used throughout this thesis.

The Kolmogorov-Smirnov Z test is a more general test that detects differences in both the locations and the shapes of the distributions. The Kolmogorov-Smirnov test is based on the maximum absolute difference between the observed cumulative distribution functions for both samples. When this difference is significantly large, the two distributions are considered different.

3.12.4 t-Test

This is a parametric test used to determine whether two means are significantly different from one another. Two-tailed tests have been used throughout the thesis.

The Independent-Samples t-Test procedure compares means for two groups of cases. Ideally, for this test, the subjects should be consistently assigned to two groups, so that any difference in response is due to the treatment (or lack of treatment) and not to other factors.

Statistics

In addition, for each variable: sample size, mean, standard deviation and standard error of the mean have been produced. For the difference in means: mean, standard error and confidence interval (the confidence level) can be specified. Tests: Levene's test for equality of variances and both pooled- and separate-variances t-Tests for equality of means have been produced.

3.12.5 Chi-square Goodness-of-Fit (Non-parametric)

This test compares observed frequencies with expected frequencies. It measures whether the distributions overlap or not. It is a test of how well a model fits the observed data. Small observed significance levels (say, less than 0.10) indicate that the model does not fit well.

3.12.6 Fisher's Exact Test

This is a non-parametric test that computes the exact probability of outcomes in a 2×2 table. It is used instead of Chi-squared where the observed frequency is 5 or less.

3.12.7 Mann-Whitney U Test

This test uses the ranks of the observations as a device for testing hypotheses about the identity of the two population distributions. Two-tailed tests are used throughout the thesis.

The Mann-Whitney U test is the most popular of the two-independent-samples tests. The observations from both groups are combined and ranked, with the average rank assigned in the case of ties. The number of ties should be small relative to the total number of observations. If the populations are identical in location, the ranks should be randomly mixed between the two samples. The number of times a score from group 1 precedes a score from group 2 and the number of times a score from group 2 precedes a score from group 1 are calculated. The Mann-Whitney U statistic is the smaller of these two numbers.

3.12.8 Spearman Rank-order Correlation Coefficient (rho)

This is a measure of the linear correlation between ranks. The closer the agreement between the rankings, the nearer rho is to 1.

The Bivariate Correlations procedure computes Spearman's rho and its significance levels. Correlations measure how variables or rank orders are related. Before calculating a correlation coefficient, the data is screened for outliers (which can cause misleading results) and evidence of a linear relationship.

Note

Significance levels are given as:

- $p < 0.05$ (significance at the 5% level) indicated with one asterisk (*);
- $p < 0.01$ (significance at the 1% level) and termed 'highly significant', indicated with a double asterisk (**);
- $p < 0.001$ (significance at the 0.1% level) and termed 'very highly significant', indicated with a treble asterisk (***);
- ns (not significant).

On a few occasions specific significance levels were reported where appropriate.

Reporting of results

The results for each of the mathematical operations are given in Chapters 6–13, which are further subdivided under two main headings: correctness and speed of response.

Chapter 14 gives details of 'instantaneous responding' across the four operations. Some 'additional behaviour' made by the participants was observed during testing and the findings are presented in Chapter 15. The performance of the dyslexics and non-dyslexics on the four operations is compared in Chapter 16.

CHAPTER 4

Experimental Precautions

4.1 Introduction
4.2 Pilot Studies
4.3 Simple Reaction Time Test
4.4 Change of Procedure and Its Justification – The Reading/Key Search Reaction Time Test
4.5 The Use of Two Trials

4.1 Introduction

The researcher wanted to know:

(1) Whether the design needed modifications.

(2) If dyslexics were slower than controls in simple reaction time; if they were, then any differences may not have been due to the sums but to an overall longer reaction time.

(3) Were they slower than controls in key search reaction time – for the same reason?

(4) How consistent would results be on separate occasions?

As a consequence, pilot studies were conducted for both Stage 1 and Stage 2 to aid in the design and two reaction time tests were installed, to check for any differences in reaction time response by groups and age bands that would have a large enough effect on the final response times in the main experiments. Two trials were built into the design in order to give greater clarity to the final results.

4.2 Pilot Studies

4.2.1 Introduction

Various problems needed solving in the design phase and the pilot studies were set up to address the following:

(1) *Time* – the aim was to make sure that the sessions weren't too long.

(2) *Order* – the participants would need to be familiarised with the type of questions and responses in the experiments.

(3) *Positioning* – of apparatus and participants.

(4) *Apparatus*

(5) *Wording* – what should be said and shown to the participants.

Pilot studies were conducted for both Stage 1 and Stage 2. The pilot study conducted prior to Stage 2 included modifications deemed important in the light of the work completed in Stage 1.

4.2.2 Stage1: Multiplication

Pilot studies led to the following decisions in Stage 1.

Time

(1) The participants should perform 144 multiplication questions in one sitting. It was found that the length of time required to perform the initial test amounted to approximately 10 to 25 minutes. The participants in this instance were all controls and it seemed very likely that some dyslexic participants might take longer.

(2) Consideration was given about how long to expose the stimuli – after pilot studies it was concluded that 22 seconds would be an appropriate length of time. Additionally, if there were no time limit per question, then the possibility of a participant pondering over some of the questions could lead to an unacceptably long trial session, with the danger of fatigue variability

occurring. Twenty-two seconds was found to be an appropriate length of time for working out the problems and it allowed the participants a sense of moving on through the test. For a more detailed rationale of this decision see Chapter 3 (section 3.6.3).

(3) A gap of 2 seconds between one question and the next would be needed to allow the screen trace to clear and to give the participant time to blink. Some participants tended to continue considering the previous question (perseveration) to confirm in their minds that they had arrived at the correct answer and this had a knock-on time effect on the following question on the screen. The 2-second interval would help to allow for a clearer mind ready for the next question. The 2-second gaps added 5 minutes to the test, which was considered reasonable.

(4) An interval between question 72 and 73 would be included. This would allow for a well-earned break, especially for the participant who did not have many number facts at his disposal. The interval could last for as long a time as the experimenter felt appropriate, and would provide a useful opportunity to reassure the participant and ask him about his background. After the interval the participant would need to press the "Enter" key twice to start off the questions again. This would serve two purposes: firstly to enable the participant to prepare himself for the next set of questions, and secondly to prevent any accidental "Enter" key pressing, initiating the next section of the questions before the participant was ready for them.

Order

(1) Because of a knock-on or perseveration effect shown in (3) above, it was decided that there should be a second trial with the questions asked in the reverse order. The computer was programmed to pivot the questions around the central point (question 144 to 73, 72 to 1, etc). Such a precaution would also strengthen the experimental design in that any potential perseveration effects would be lessened while at the same time more information would be provided for analysis.

(2) Pre-test sessions seemed desirable as a good way to familiarise all the participants equally with the nature of the responses that would be required of them.

Positioning

Pre-tests would also allow the participants to develop a regular pattern of handedness in their responses. For the experimenter to insist on the use of the left or right hand was considered unwise since the participant's attention would already be fully occupied and this might distract those who had to think particularly hard about certain answers. For this reason also the participant's chair was placed centrally to the screen and the area of the keyboard to be used, enabling the participant to use his preferred hand or hands to operate the computer. A keyboard cover was specifically made for this research, strategically positioned over the unused keys to avoid the distraction of the additional unwanted symbols printed on the top of the keys. The keys to be operated were designed by Amstrad in a pale shade of grey while the all-important "Enter" key was in darker grey.

Apparatus

There was a choice of two screens – the Amstrad built-in liquid-crystal display, or the Sinclair white-on-black monitor. The latter was chosen for clarity of vision in the prevailing circumstances.

Wording

The wording used in the instructions is given in Chapter 3 (see section 3.8.1).

4.2.3 Stage 2: Division, Addition and Subtraction

Pilot studies led to the following decisions in Stage 2.

Time

(1) A pilot study was trialled on a range of age groups including adults and the participants were encouraged to give their opinion on the questions, their style of presentation, number of questions and equipment. The length of time that it took the participant to complete half of each Main Experiment and the total time for the Set Pre-test, the Random Pre-test and Main Experiment was checked and found to be adequate for the research. The number of questions was then set at 144 (division) and 150 (addition and also subtraction).

(2) In Stage 2 both the Addition and Subtraction experiments required the participant to perform two trials in the same way as Stage 1. These were achieved in one sitting with questions pivoted around the central point separated by an interval.

(3) The Division experiment contained just one trial since Pilot Studies revealed that the length of time, and number of visits required by the individual participant to perform Stage 2, was sufficient.

Checks were made with the trial data from Stage 1 to see if this decision would affect the final outcome of the experiment. The dataset results for Stage 1 revealed both positive and negative differences between trials but these were so small as to not affect the outcome of the results.

(4) Modifications were made as a result of findings in Stage 1. The use of an auditory 'beep' accompanied by a visual change of screen colour was deemed necessary as a way of increasing awareness of the onset of the next question. It had been found that some participants in Stage 1 had been unaware of the appearance of the next question in a 'missed' situation where the participant had exceeded the maximum display time of 22 seconds. The experimenter had been alerting the participant in such cases of the next question onset. The use of such a multi-sensory prompt proved to be more efficient. Length of beep was made at 1 second and terminated as the question appeared. This was made consistent throughout all testing.

Order of information

A display of preliminary details was established that needed completing prior to experimentation. For thoroughness and clarity the following details were presented on the screen once either the Reaction Test, Addition, Subtraction or Division Tests had been selected from the Main Menu.

- Subject's Log number is .... (The computer gave this automatically)
- Code for subject's school .... (Experimenter keyed this in)
- Grouping code for subject.............. (Experimenter keyed this in)
- Subject's first name? .... (Experimenter keyed this in)
- Subject's middle name?................. (Experimenter keyed this in)
- Subject's surname?......................... (Experimenter keyed this in)
- Subject's age in years?................... (Experimenter keyed these in)

  And months? ....
- The subject's full name is .... (At this point the computer clarified the responses typed in by the researcher)
- And they were .... years and .... months old.
- Are all details correct? Yes / No

  (Experimenter indicates the reply – If 'no' then points two to seven are re-run.)
- Question ONE will start when you press "ENTER".

The experimenter then changed places with the participant who was then positioned in front of the screen and numeric keypad comfortably.

Positioning

(1) *Numeric pad usage.* A numeric pad was obtained which could be positioned independently from the computer. A way was sought to place the numeric pad centrally to the computer screen after initial participant details had been typed in on the main keypad. A base platform was devised out of wood to act as a plinth to safely cover the main keyboard with the minimum amount of time

and disruption. This enabled the numeric pad to be placed in the most comfortable position for left- or right-handed participants due to its portable lightweight nature. Pilot studies revealed that participants needed padding on the wooden base, especially for their wrists that rested on the base as they were working. Pale green carpet was then affixed to the base top. Psychologically green was thought to portray a calming influence and a 'go' situation. This adjustment was much appreciated by the pilot participants.

(2) *Number display on the screen.* The style of numbering was considered for best usage and clarity. The numbers 6 and 9 can be confused due to their similar shape. The computer screen display was amended to present these two numbers as visually dissimilar.

Wording

The wording used in the instructions is given in Chapter 3 (see sections 3.9.1, 3.10.1 and 3.11.1).

4.2.4 SA Controls

It was decided to exclude the young spelling controls from Stage 2. This decision was supported by a study of the type of questions to be asked in the Division experiment, since the knowledge of all division facts up to 144/12 is not usually covered so early in a pupil's education. It was discovered that in order to find spelling controls matched with the dyslexic participants on spelling score, this would involve a search for participants whose spelling scores fell within the parameters listed in Table 4.1.

Table 4.1 Spelling score ranges for the three age-bands in the dyslexic group

Dyslexic group age band	*Spelling score range*	*Youngest spelling age*
Young	16—45	6 years 7 months
Medium-age	29—55	7 years 11 months
Old	17–72	6 years 8 months

Such a low spelling age across all the age ranges indicated that spelling matched participants would be many years behind the chronological ages of the dyslexic participants. Results in Stage 1 indicated poorer performance overall by the spelling controls in mean response times across age bands when compared to both the dyslexic group and the CA control group. Preliminary reaction-time tests in Stage 1 showed that reaction-time differences between the three groups were so small as to not interfere with the main results (see section 4.3.4).

A decision was therefore made to direct further attention to the performance of the dyslexic and CA control groups (hereon called controls) and study how they compared to each other on the Addition, Subtraction and Division experiments. Different groups of participants took part in Stage 1 and Stage 2.

4.3 Simple Reaction Time Test

4.3.1 Introduction

This reaction time test was given to participants in Stage 1 in conjunction with the Multiplication experiment. It was designed to test for any differences between the experimental groups and age bands in participant response to the appearance of a stimulus in the centre of the computer screen. If any significant difference were to be found, then the speed data gained from the Multiplication experiment could then be adjusted to take these differences into account.

4.3.2 Apparatus – the React Working Disk for Stage 1

This disk was created in order to monitor the reaction time of all participants to the computer screen read-out with their consequent response on the keypad. Thus analysis of reaction time could be monitored across all participant groups and age bands in a search for possible variance. On pressing the "Enter" key, the participant waited for a single star to appear in the centre of the screen. The moment this was sighted, the participant immediately pressed the "Enter" key again and then waited, with eyes on the screen, for the next star to appear. The disk was designed so that ten stars were presented individually in succession, with varying time intervals ranging from 1 second to 10 seconds from the operation of the "Enter" key to the appearance of the next star.

The order of the 'varying time intervals' was as follows:

4 sec, 10 sec, 8 sec, 1 sec, 6 sec, 2 sec, 9 sec, 3 sec, 7 sec, 5 sec

The participant was thus unable to predict the precise moment of the appearance of a star. The computer registered the participant's reaction time to each star presented.

4.3.3 Method – Instructions

The instructions are given in Appendix F.

The test lasted for only a few minutes.

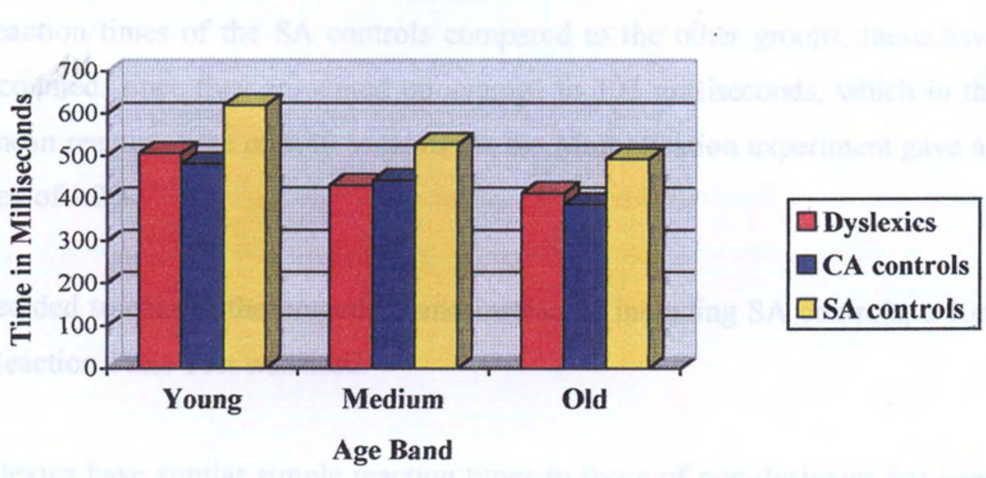
4.3.4 Results

The results presented in Table 4.2 and Figure 4.1 are for the reaction time test taken prior to the main experimental test. In this test, each participant was monitored for his reaction time to the computer screen read-out and his consequent response on the keypad.

Table 4.2 Mean reaction time and standard deviation (in milliseconds) for the three groups and the three age-bands

Group	*Age-band*					
	Young		*Medium*		*Old*	
	Mean	*Standard deviation*	*Mean*	*Standard deviation*	*Mean*	*Standard deviation*
Dyslexics	506	+/– 48.55	431	+/– 58.37	412	+/– 47.93
CA controls	481	+/–100.75	442	+/– 37.46	386	+/– 40.03
SA controls	619	+/–116.43	528	+/– 74.58	492	+/– 72.08

Figure 4.1 Mean reaction times for the 3 groups and 3 age bands



There was a slight decrease in reaction time between the young to medium-age and the medium-age to old age bands.

These mean reaction times showed only minor differences between groups and between age bands and they would not contribute significantly to the differences revealed in the main experiment.

It is interesting to note that the medium-age CA controls took longer to respond than the medium-age dyslexics.

Analysis of variance showed an age effect ($F = 16.89$, df.2, $p < 0.001$) and a group effect ($F = 21.50$, df.2, $p < 0.001$) but no significant interaction in respect of age and group ($F = 0.48$, df.4, ns). Those in the young age group were significantly slower than those in the medium age band ($t = 2.86$, df.58, $p < 0.004$) and participants in the medium age band were marginally slower than those in the old age band ($t = 2.03$, df.58, $p < 0.048$). The SA controls were slower than the dyslexics ($t = 4.39$, df.58, $p < 0.001$) and than the CA controls ($t = 4.75$, df.58, $p < 0.001$), but there was no significant difference between the dyslexics and the CA controls ($t = 0.73$, df.58, ns).

4.3.5 Conclusion

It follows from these results that any differences between dyslexics and CA controls cannot be the consequence of differences in simple reaction time. With regard to the longer reaction times of the SA controls compared to the other groups, these have been discounted, since they amounted on average to 103 milliseconds, which in the overall mean reaction time of 8.40 seconds for the Multiplication experiment gave an inaccuracy of 1.2%.

It was decided to change the procedure and instead of including SA controls, a Key Search Reaction Time Test was used.

That dyslexics have similar simple reaction times to those of non-dyslexics has been reported in a number of studies (Nicolson and Fawcett, 1994a) and can now be regarded as firmly established.

4.4 Change of Procedure and Its Justification - The Reading/Key Search Reaction Time Test

4.4.1 Introduction

The dyslexics were no slower than the CA controls (ns) in simple reaction time. The SA controls were, however, significantly slower ($p < 0.001$) than the dyslexics. As a result it was decided to exclude the SA controls and instead use a different experimental precaution – that of checking for differences in reading speed and motor control. Thus there was to be one control group and the CA controls are referred to as controls.

This reaction test was designed to discover if the dyslexic participants were slower at reading the stimuli. If one claims that dyslexics have some difficulty or weakness other than for reading, one needs to compare them with others of the same reading level. If dyslexics respond equally as fast on the Reading/Key Search Reaction Time Test but perform worse on the speed of calculating, then their weakness in relation to the controls can't be due to lack of reading skills. In this reaction time test the calculation element was omitted and participants were tested on reading and motor tasks – copying a display where no calculation was involved. This safeguard controlled not only for slowness in reading skills but slowness in motor skills.

4.4.2 Apparatus – the React Working Disk for Stage 2

It was thought necessary to mimic the main experiment as far as possible in testing reaction time. This was better achieved by presenting one- and two-digit numbers for response rather than a single star. By so doing, the participant needed to read the number from the screen, hold on to it in short-term memory and search for the duplicate number/s on the numeric keypad, type the number/s and then press the "Enter" key. The numbers that were chosen represented all the possible digits that could be pressed on the numeric keypad from 0 to 9 as well as paired numbers positioned the furthest apart on the numeric keypad itself. This was so as to test for reading skill and search time while the number was being held in memory.

There were 40 one- and two-digit numbers presented as follows:

8	73	4	81	7	64	3	92	0	39
6	50	9	28	2	17	5	46	1	70
3	83	6	94	0	34	7	27	4	76
8	90	1	49	5	19	2	67	9	43

Thus the numbers ranged from 0 through to 94. Indeed any response in Stage 2 would only require a maximum of two digits to be pressed where no answer exceeded 99.

Only one press on the "Enter" key was necessary to start the test. Once the number appeared on the screen, it remained visible even while the participant typed in that number. As the participant typed, the screen remained the same. If the participant typed in the wrong number this was not evident on the screen since only the initial/target number remained visible. Pilot studies had shown that some participants hesitated in pressing the "Enter" key because they looked up at the screen to check that they had typed in the correct number. Thus the modification here of only having the number displayed and no more enabled the participants to type freely without any variable of double-checking. Depression of the "Enter" key moved the presentation on to the next number.

White digits were displayed on a black background. On pressing the "Enter" key the display on the screen faded in 0.1 seconds. The screen then became white for 1.5 seconds. As the screen then turned from white to black to signal an impending number presentation, a 0.3 second beep accompanied this. A time of 0.1 seconds then elapsed before the next number was presented. A total gap time of 2 seconds therefore occurred between the pressing of the "Enter" key and the presentation of the next number on the screen.

For recording purposes the first two digits pressed prior to the depression of the "Enter" key are those that were recorded in the results where the number presented had two digits. If only one digit was presented then the first digit pressed would be recorded. The computer had been programmed to measure the time lapse between each individual key being depressed and combining those times to present a total for analysis. The reaction times are given to a hundredth of a second.

4.4.3 Analysis of Target Numbers

Forty target numbers were presented alternately; 20 were one-digit numbers and 20 were two-digit numbers.

Each one-digit number was repeated twice, once in the first 20 numbers and once in the second 20 numbers. The presentation was random so that the participant was unable to anticipate a forthcoming number.

The target numbers selected are analysed by decades (Table 4.3) and units (Table 4.4).

Table 4.3 Breakdown of the double-digit target numbers into decades

Target numbers by decade								
10s	20s	30s	40s	50s	60s	70s	80s	90s
17	28	39	46	50	64	73	81	92
19	27	34	49		67	70	83	94
			43			76		90

Total 20

Table 4.4 Representation of the 'units' in the Reading/Key Search Reaction Time Test

	Units									
	0	1	2	3	4	5	6	7	8	9
Frequency	5	3	3	5	5	2	4	5	3	5

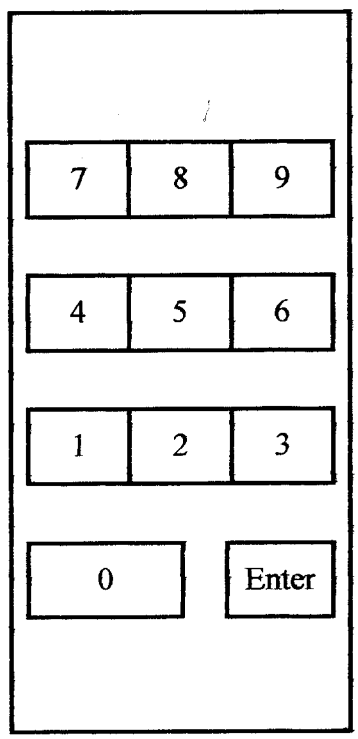
Total 40

The 5 was not featured in the 'units' of the two-digit numbers since it lay in the centre of the number keypad and therefore was not a distance from any other number except 0 when pressing a response. Hence the number 50 is included.

The number-pairs chosen for two-digit numbers are those that are separated by at least one digit on the number keypad. In this way no doubletons were to be included, for example '44'.

The layout of the number keypad is given in Figure 4.2.

Figure 4.2 Number keypad



There are eight categories:

(1) Straight down – 50, 70.

(2) Straight up – 39, 28, 17.

(3) Straight across from left to right – 46.

(4) From left to right of which the start position is lower – 49, 19.

(5) From left to right of which the start position is higher – 73, 83, 76, 43.

(6) From right to left where the start position is lower – 34, 27, and 67.

(7) From right to left where the start position is higher – 81, 92, 94 and 90.

4.4.4 Method – Instructions

Each participant was given the following instructions:

(1) 'This is a Reaction Time Test to see how quickly you can respond to a number, which will appear on the screen here. [Experimenter points to the centre of the screen.] This could be a one-digit or two-digit number.'

(2) 'When you see the number appear on the screen, you type the number on this keypad [experimenter indicates the numeric keypad] and then press the "Enter" key to stop the clock inside the computer. You are being timed to see how quickly you respond to seeing the number on the screen, typing it in and then pressing the "Enter" key to stop the clock.'

(3) 'It is important that you press the "Enter" key after your number to show that you have completed your response.'

(4) 'There are forty numbers that will appear one at a time and the test will only take about two minutes to complete.'

(5) 'Remember that you are being timed to see how quickly you respond. Start when you are ready by pressing the "Enter" key.'

The Reading/Key Search Reaction Time Test was given to all the participants during one of their visits.

4.4.5 Results

The mean Reading/Key Search Reaction Time is recorded in Table 4.5 in milliseconds for the two groups and three age bands. Standard deviation is given in brackets. The means recorded were found by obtaining a mean for each individual and then aggregating these means to find each outcome recorded here.

Table 4.5 Mean Reading/Key Search Reaction Times (in milliseconds) for the two groups and three age bands

Group	*Age band*		
	Young	*Medium*	*Old*
Dyslexic	215.5 (23.9)	185.9 (12.6)	169.9 (9.8)
Control	187.9 (14.6)	175.5 (19.4)	164.8 (8.8)

The standard deviation pattern was mixed, but for the older age band the standard deviations were tighter, indicating not so much spread of variation.

A multifactorial ANOVA indicated a significant difference in the Reading/Key Search Reaction Time between groups ($p < 0.001$) and ages ($p < 0.000$), where the latter impact was greater because of age. The ANOVA for group and age was not significant ($p = 0.071$).

With regard to the longer reaction times of the dyslexics, these were discounted, since they amounted on average to 14.37 milliseconds, which in the overall mean reaction time of 7.89 seconds for the Division experiment gave an inaccuracy of 0.18%.

The percentage of inaccuracy for each group age band is given in Table 4.6. The mean Reading/Key Search reaction times were compared to the mean response times for the Division experiment.

Table 4.6 Mean Reading/Key Search reaction times compared to the mean response time for the two groups and three age bands on division and presented as a percentage

Group	*Age band*		
	Young	*Medium*	*Old*
Dyslexics	1.6%	2.4%	2.2%
Controls	2.4%	3.1%	3.6%

The percentages given in Table 4.6 represent a small level of inaccuracy.

Therefore as a precaution, the researcher had checked the key search reaction time and found that it was small enough to be ignored.

4.4.6 Conclusion

Should the individual Reading/Key Search reaction times be subtracted from the individual scores obtained in Stage 2?

Two key points support the argument for keeping the scores as found. The first point is that the order of the magnitude of the difference is not large enough to affect the results when comparing the dyslexic and control performances. Secondly, it is of interest to discover how all participants fared in the whole task from beginning to end. All participants in each experimental group performed the same tasks.

Two issues need to be taken into account. The first is materiality as discussed above. This is an extremely small proportion of the overall reaction time. Secondly, there is a methodological issue about whether one should take the average difference in reaction time for Trial 1 and Trial 2 for categories of participants or whether one should use the individual difference scores for each participant, which could be deemed to create greater distortion.

It was decided not to adjust any findings in the light of the Reading/Key Search Reaction Time Test.

4.5 The Use of Two Trials

A further experimental precaution was taken by conducting two trials on the Multiplication, Addition and Subtraction experiments enabling a comparison to be made between the trials and thus checking for consistency of response by the participants. One trial was performed on the Division experiment in the light of these findings and also in consideration of the participant effort required.

Details of Trial 1 and Trial 2 are given in Chapter 5.

CHAPTER 5

Trial 1 and Trial 2

5.1 Introduction

5.2 Stage 1 – Multiplication

5.3 Stage 2 – Addition

5.4 Stage 2 – Subtraction

5.5 Findings for the Dataset

5.1 Introduction

The aim of this chapter is to present the results from Trial 1 and Trial 2 and to justify the use of the mid-point response times for analysis in Chapters 10 to 13 on 'Speed'. The mid-point findings are appropriate since the difference between the two trials is quite minimal as will be explained. Two trials were conducted for the Multiplication, Addition and Subtraction experiments. Participants performed one trial for the Division experiment, in order to minimise testing overload.

The first and second trials are referred to as the Dataset.

5.2 Stage 1 – Multiplication

5.2.1 Introduction

Two main findings are reported: firstly for the entire research population, giving an indication of trend and thus determining the direction of further analysis, and secondly for the performance of the experimental groups on both trials. The SA control group is included in the results.

5.2.2 The Entire Research Population – Multiplication

Each participant was given the same task twice over. Trial 1 comprised 144 questions presented in the same sequence for each participant. The sequence of questions was selected at random so that the participants could not anticipate any of the questions. The second trial consisted of the same 144 questions but in the reverse order. Thus in Trial 1 the order of the questions was 1 – 72 followed by an interval, then 73 - 144 and in Trial 2 the order was 144 - 73 followed by an interval, then 72 - 1.

Table 5.1 Multiplication Dataset results for the entire research population (in seconds)

Dataset	*Mean*	*Standard deviation*	*Cases*
Trial 1	8.54	7.61	12,960
Trial 2	8.26	7.57	12,960

The difference between the means for the two trials was 0.28 seconds.

The response times for Trial 1 and Trial 2 were significantly different ($t = 2.93$, $df = 25918$, $p = 0.003$) where the second time was faster.

It was decided that if the time-interval mid-way between that of Trial 1 and Trial 2 were treated as the participant's time score on that particular task, the loss of accuracy would be so minimal that it could easily be ignored.

5.2.3 Multiplication Dataset Results for the Groups

The results are more persuasive when the details for the individual groups are considered.

A study of Trial 1 – Trial 2 (dyslexics) and Trial 1 – Trial 2 (controls) was conducted to find out if the overall minimal difference was present within each group.

The results are displayed in Table 5.2. All age bands are taken together and the standard deviation is given in brackets.

Table 5.2 Dataset Results for the groups on multiplication – mean response time (in seconds)

	Dyslexics	*CA controls*	*SA controls*
Trial 1	8.95 (7.78)	5.77 (6.07)	10.89 (7.95)
Trial 2	8.85 (7.71)	5.50 (5.90)	10.44 (8.07)
Difference (seconds)	0.1	0.27	0.45

There was a significant difference between the dyslexic group, the CA control group and the SA control group on Trial 1 ($F (2,12957) = 538.78$, $p < 0.001$).

There was a significant difference between the dyslexic group, the CA control group and the SA control group on Trial 2 ($F (2,12957) = 517.71$, $p < 0.001$).

t-Tests comparing Trial 1 and Trial 2 gave the following results:

- CA control group ($t = 2.158$, $df = 8638$, $p < 0.05$).
- Dyslexic group ($t = 0.582$, $df = 8638$, ns).
- SA control group ($t = 2.63$, $df = 8638$, $p < 0.01$).

Thus there was no significant difference between Trial 1 and Trial 2 for the dyslexic group.

The difference between Trial 1 and 2 for each of the three groups was very small. When it is considered that each group contains 30 participants, then by further subdividing by 30, one ends up with a very small figure that is almost negligible in view of the main research.

Therefore, while there were significant differences found, in terms of the amount of time that this represented these were small enough to be ignored. As a consequence, it was decided to take the mid-point between Trial 1 and Trial 2 as the measure of central tendency for the three groups, whilst using the full array of data for subsequent analysis.

5.3 Stage 2 – Addition

5.3.1 Introduction

As with the Multiplication experiment, each participant was given the same task twice over in order to determine how much fluctuation there was between different trials. The results are presented in Tables 5.3 and 5.4. The SA controls only took part in Stage 1 and were therefore not included in the Addition, Subtraction or Division experiments.

Each of the 60 participants took part in two trials. The first trial comprised 75 questions followed by an interval, and then Trial 2 was conducted with the same 75 questions but this time in reverse order. All participants were exposed to all the questions in the same sequence. The sequence of questions from the five addition categories was selected at random so that the participants could not anticipate any of the questions.

5.3.2 The Entire Research Population – Addition

An initial investigation was done on the results for the two trials taking groups and age bands together. Thus an overall trend would be revealed which would steer further analysis.

Table 5.3 Addition Dataset results for the entire research population (in seconds)

	Mean	*Standard deviation*	*Cases*
Trial 1	9.31	2.81	60
Trial 2	9.09	2.70	60

The difference between the means for the two trials was 0.22 seconds.

The response times for Trials 1 and 2 were significantly different ($t = 2.478$, $df = 59$, $p < 0.05$).

It was decided that if the time-interval mid-way between that of Trial 1 and Trial 2 were treated as the participant's time score on that particular task, the loss of accuracy would be so minimal that it could easily be ignored.

5.3.3 Addition Dataset Results for the Groups

A study of Trial 1 – Trial 2 (dyslexics) and Trial 1 – Trial 2 (controls) was conducted to find out if the overall minimal difference was present within each group.

The results for the two groups are given in Table 5.4. All age bands are taken together and the standard deviation is given in brackets.

Table 5.4 Dataset results for the groups on addition – mean response times in seconds

	Dyslexics	*Controls*
Trial 1	10.56 (3.11)	8.05 (1.75)
Trial 2	10.38 (3.00)	7.80 (1.55)
Difference (seconds)	0.18	0.25

There was a significant difference between the dyslexic group and the control group on Trial 1 ($t = 3.860$, $df = 58$, $p < 0.001$).

There was a significant difference between the dyslexic group and the control group on Trial 2 ($t = 4.189$, $df = 58$, $p < 0.001$).

A paired sample t-Test showed that there was a significant difference between Trial 1 and Trial 2 for the control group ($t = 2.129$, $df = 29$, $p < 0.05$) but there was no significant difference for the dyslexic group ($t = 1.392$, $df = 29$, ns).

The difference between Trials 1 and 2 for each of the groups was very small. When it is considered that each group contains 30 participants, then by further subdividing by 30, one ends up with a very small figure that is almost negligible in view of the main research.

Therefore, while significant differences were found, in terms of the amount of time that this represented these were small enough to be ignored. As a consequence, it was decided to take the mid-point between Trial 1 and Trial 2 as the measure of central tendency for the two groups, whilst using the full array of data for subsequent analysis.

5.4 Stage 2 – Subtraction

5.4.1 Introduction

As with the Multiplication and Addition experiments, each participant was given the same task twice over. The results are presented in Tables 5.5 and 5.6.

Each of the 60 participants took part in two trials. The first trial comprised 75 questions followed by an interval, and then Trial 2 was conducted with the same 75 questions but this time in reverse order. All participants were exposed to all the questions in the same sequence. The sequence of questions from the five subtraction categories were selected at random so that the participants could not anticipate any of the questions.

5.4.2 The Entire Research Population – Subtraction

The results for both trials are recorded in Table 5.5 for the entire research population.

Table 5.5 Subtraction dataset results for the entire research population (in seconds)

	Mean	*Standard deviation*	*Cases*
Trial 1	10.45	2.95	60
Trial 2	9.93	2.66	60

The difference between the means for the two trials was 0.52 seconds.

The response times for Trials 1 and 2 are significantly different ($t = 4.564$, $df = 59$, $p < 0.001$).

It was decided that there would be no significant loss of accuracy if the time-interval mid-way between that of Trial 1 and Trial 2 were treated as the participant's time score on that particular task.

5.4.3 Subtraction Dataset Results for the Groups

A study of Trial 1 – Trial 2 (dyslexics) and Trial 1 – Trial 2 (controls) was conducted to find out if the overall minimal difference was present within each group. The results for the two groups are given in Table 5.6. All age bands are taken together and the standard deviation is given in brackets.

Table 5.6 Dataset results for the groups on subtraction – mean response times in seconds

	Dyslexics	*Controls*
Trial 1	11.75 (3.07)	9.15 (2.19)
Trial 2	10.94 (2.59)	8.92 (2.36)
Difference (seconds)	0.81	0.23

There was a significant difference between the dyslexic group and the control group on Trial 1 ($t = 3.765$, $df = 58$, $p < 0.001$).

There was a significant difference between the dyslexic group and the control group on Trial 2 ($t = 3.166$, $df = 58$, $p < 0.001$).

A paired sample t-Test showed that there was no significant difference between Trial 1 and Trial 2 for the control group ($t = 1.893$, $df = 29$, ns) but there was a significant difference for the dyslexic group ($t = 4.513$, $df = 29$, $p < 0.001$).

The difference between Trials 1 and 2 for each of the groups was very small. When it is considered that each group contains 30 participants, then by further subdividing by 30, one ends up with a very small figure that is almost negligible in view of the main research.

Therefore, while significant differences were found, in terms of the amount of time that this represented these were small enough to be ignored. As a consequence, it was decided to take the mid-point between Trial 1 and Trial 2 in the case of the two groups.

The difference between the two trials was not thought large enough to warrant any alternative treatment of the data.

5.5 Findings for the Dataset

The findings on the Dataset for Multiplication, Addition and Subtraction show that any difference between Trial 1 and Trial 2 per group, or any difference between groups on trials, is small enough to justify the use of the mid-point time for analysis of response times on all three operations. Since the first–second trial differences were minimal in these three operations, it is reasonable to assume they would also have been minimal in the case of Division.

Part III

Results of Main Experiments

Correctness

CHAPTER 6

Correctness on Multiplication Tasks

6.1 Aims of This Chapter

6.2 Overall Comparisons

6.3 Tasks Within Multiplication

6.4 Comparing Age Bands Within the Separate Groups

6.5 Order of Difficulty

6.6 Special Number Combinations in Multiplication

6.7 Chapter Summary – Questions Answered

6.1 Aims of This Chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of multiplication:

(1) Do dyslexics make fewer correct responses than non-dyslexics?

(2) Do younger dyslexics make fewer correct responses than older dyslexics?

(3) Are there any special number combinations that are more likely than others to generate errors?

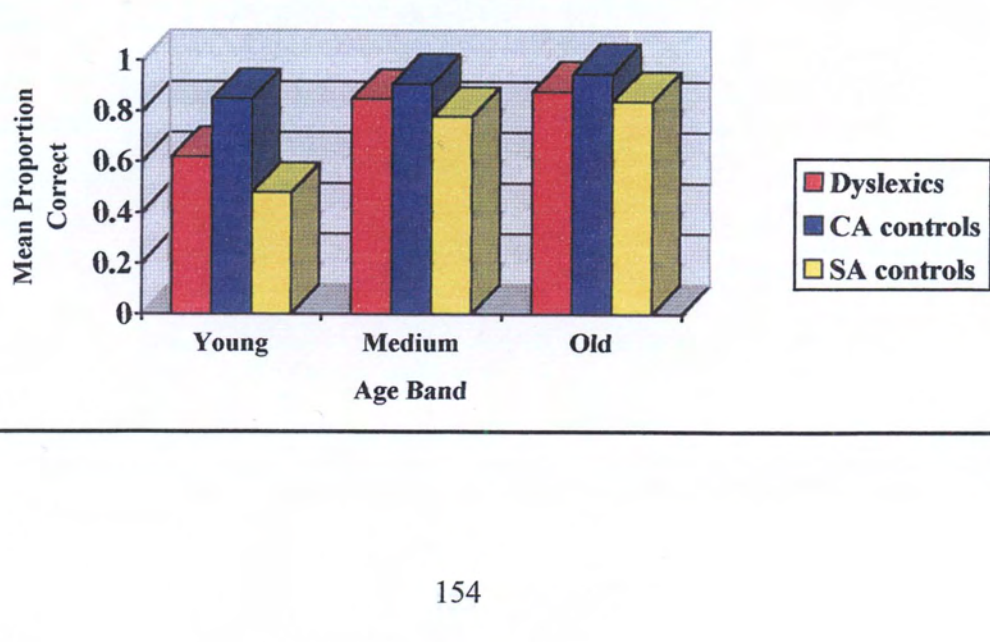
6.2 Overall Comparisons

A summary is provided in Table 6.1 and illustrated in Figure 6.1.

Table 6.1 Mean proportion correct for each group and age band on multiplication

Age	*Group*	*Mean proportion correct*	*Standard deviation*
Young	Dyslexics	0.62	0.16
	CA controls	0.85	0.09
	SA controls	0.48	0.23
Medium	Dyslexics	0.85	0.07
	CA controls	0.91	0.03
	SA controls	0.78	0.17
Old	Dyslexics	0.88	0.05
	CA controls	0.95	0.02
	SA controls	0.84	0.09

Figure 6.1 Mean proportion of correct responses for each group and age band



An analysis of variance on the data reveals the following overall results:

- An age effect ($F(2, 81) = 32.76$, $p < 0.001$)
- A group effect ($F(2, 81) = 21.38$, $p < 0.001$)
- An age and group effect ($F(4, 81) = 3.69$, $p < 0.008$)

Analysis of variance tables are presented in Appendix F1.

Post hoc tests using Tamhane show the following:

- Comparing young and medium age bands ($p < 0.001$)
- Comparing young and old age bands ($p < 0.001$)
- Comparing medium and old age bands (ns)
- Comparing SA controls and the CA controls ($p < 0.001$)
- Comparing CA controls and the dyslexics ($p < 0.001$)
- Comparing SA controls and the dyslexics (ns)

6.3 Tasks Within Multiplication

A summary of the analysis of variance is shown in Table 6.2 with post hoc tests presented in Table 6.3.

Table 6.2 Analysis of variance (between-subjects effects) showing the F values and significant differences in mean response times between groups, age bands and intercept of groups and age bands

Multiplication table	*Group*	*Age band*	*Group and age band*
1	19.254 ***	22.901 ***	14.075 ***
2	31.174 ***	75.693 ***	14.506 ***
3	63.344 ***	81.056 ***	9.911 ***
4	68.630 ***	103.831 ***	14.489 ***
5	40.668 ***	65.102 ***	14.773 ***
6	77.854 ***	99.192 ***	7.629 ***
7	88.911 ***	95.055 ***	15.826 ***
8	89.987 ***	113.026 ***	4.912 ***
9	80.761 ***	120.158 ***	6.301 ***
10	21.666 ***	61.782 ***	14.070 ***
11	53.846 ***	91.998 ***	19.235 ***
12	57.972 ***	120.182 ***	10.488 ***
	F (2,2151)	F (2, 2151)	F (4, 2151)

Significance levels key for Tables 6.2 and 6.3:

*** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

Table 6.3 Post hoc tests (Tamhane)

Multiplication table	*Group comparisons*			*Age band comparisons*		
	D/CA	*D/SA*	*CA/SA*	*Y/M*	*Y/O*	*M/O*
1	***	ns	***	***	***	ns
2	***	**	***	***	***	ns
3	***	***	***	***	***	ns
4	***	***	***	***	***	ns
5	***	***	***	***	***	ns
6	***	***	***	***	***	**
7	***	*	***	***	***	*
8	***	***	***	***	***	**
9	***	***	***	***	***	*
10	***	ns	***	***	***	ns
11	***	***	***	***	***	***
12	***	*	***	***	***	*

Key: D (dyslexic), CA (CA control), SA (SA control), Y (young), M (medium-age), O (old).

Each participant answered 288 multiplication questions (both trials together) and therefore 24 questions for each of the multiplication tables. The total number of possible correct responses for each multiplication table, per group/age band, is 240 (24 questions × 10 participants). The results are displayed in Tables 6.4, 6.5 and 6.6, and illustrated in Figures 6.2, 6.3 and 6.4.

Table 6.4 Number of correct responses made by the three groups in the young age band, broken down by table

Multiplication table	*Young age band*		
	Dyslexics	*CA controls*	*SA controls*
1	222	232	187
2	196	224	160
3	163	216	134
4	150	210	108
5	185	217	136
6	126	194	96
7	109	202	79
8	101	175	80
9	108	182	84
10	200	225	168
11	141	206	97
12	89	170	65

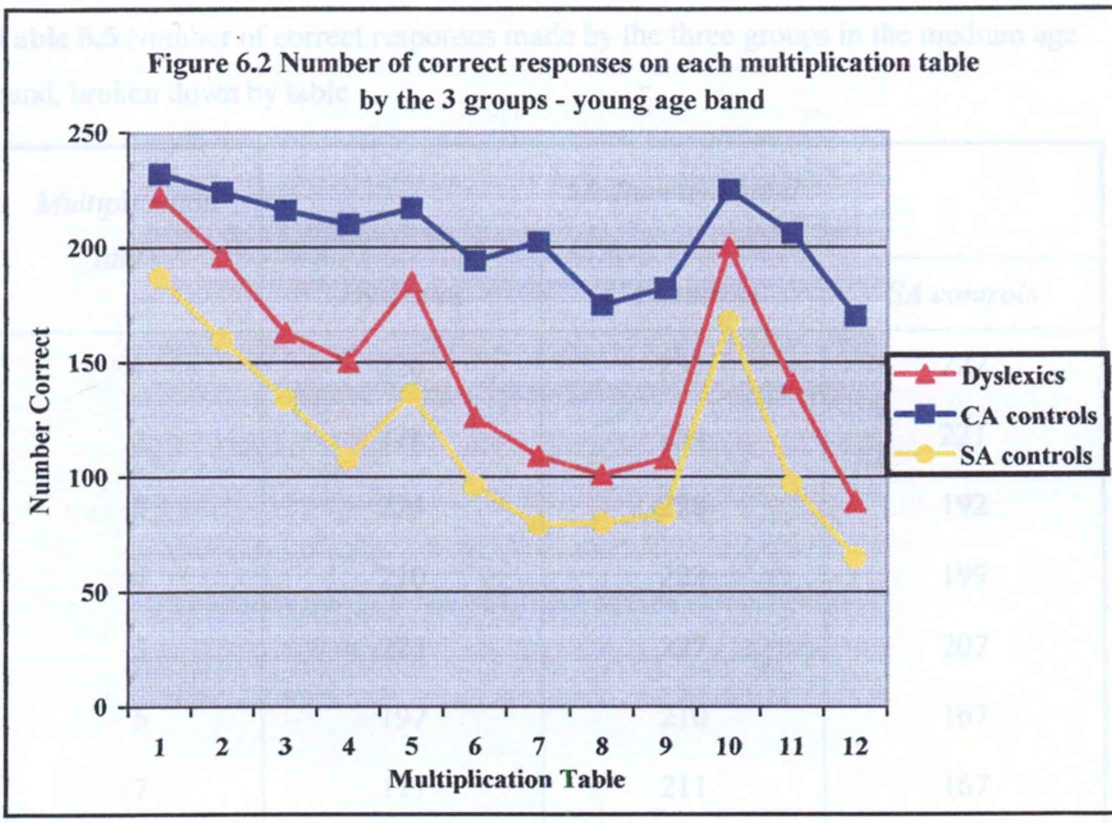


Figure 6.2 Number of correct responses on each multiplication table by the 3 groups - young age band

A Chi-squared was performed for the three groups in the young age band that showed significantly different performances for the three groups.

Chi-squared = 66.92, df = 22, $p < 0.001$.

Figure 6.2 illustrates that the performance of the SA controls followed or 'shadowed' that of the dyslexics but with less number of correct responses on each multiplication table.

Table 6.5 Number of correct responses made by the three groups in the medium age band, broken down by table

Multiplication table	*Medium age band*		
	Dyslexics	*CA controls*	*SA controls*
1	226	235	227
2	228	234	221
3	224	228	192
4	210	223	199
5	223	227	207
6	197	210	167
7	177	211	167
8	175	212	149
9	183	217	161
10	223	233	226
11	204	206	176
12	173	193	159

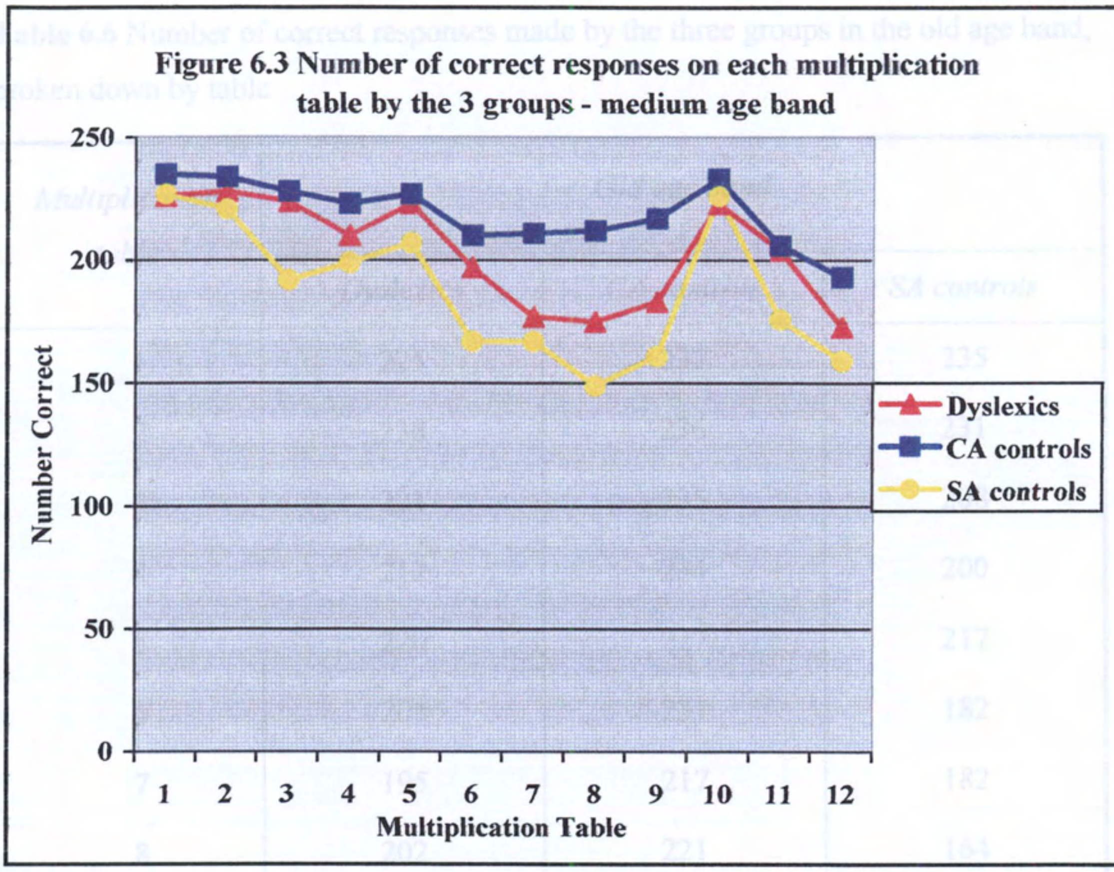


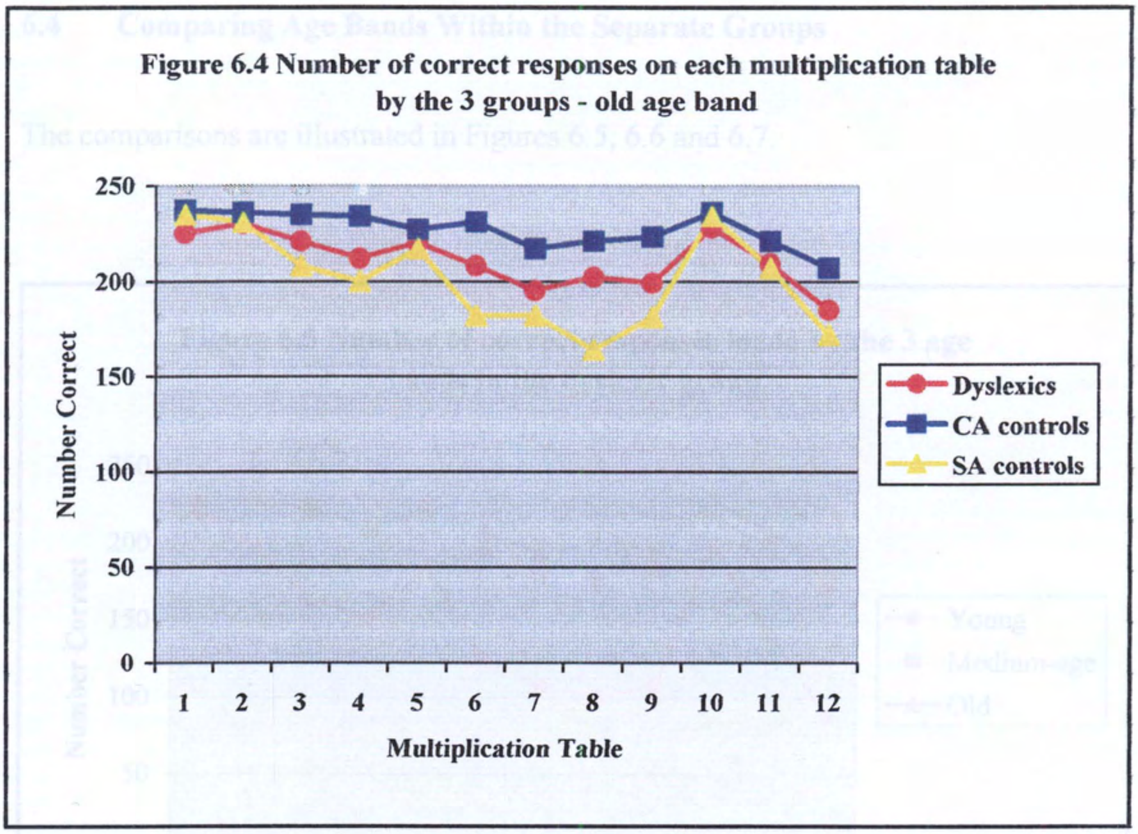
Figure 6.3 Number of correct responses on each multiplication table by the 3 groups - medium age band

A Chi-squared was performed for the three groups in the medium-age band that showed no significantly different performances for the three groups.

Chi-squared = 14.365, df = 22, ns.

Table 6.6 Number of correct responses made by the three groups in the old age band, broken down by table

Multiplication table	*Old age band*		
	Dyslexics	*CA controls*	*SA controls*
1	225	237	235
2	230	236	231
3	221	235	208
4	212	234	200
5	220	227	217
6	208	231	182
7	195	217	182
8	202	221	164
9	199	223	181
10	228	236	234
11	209	221	207
12	185	207	172

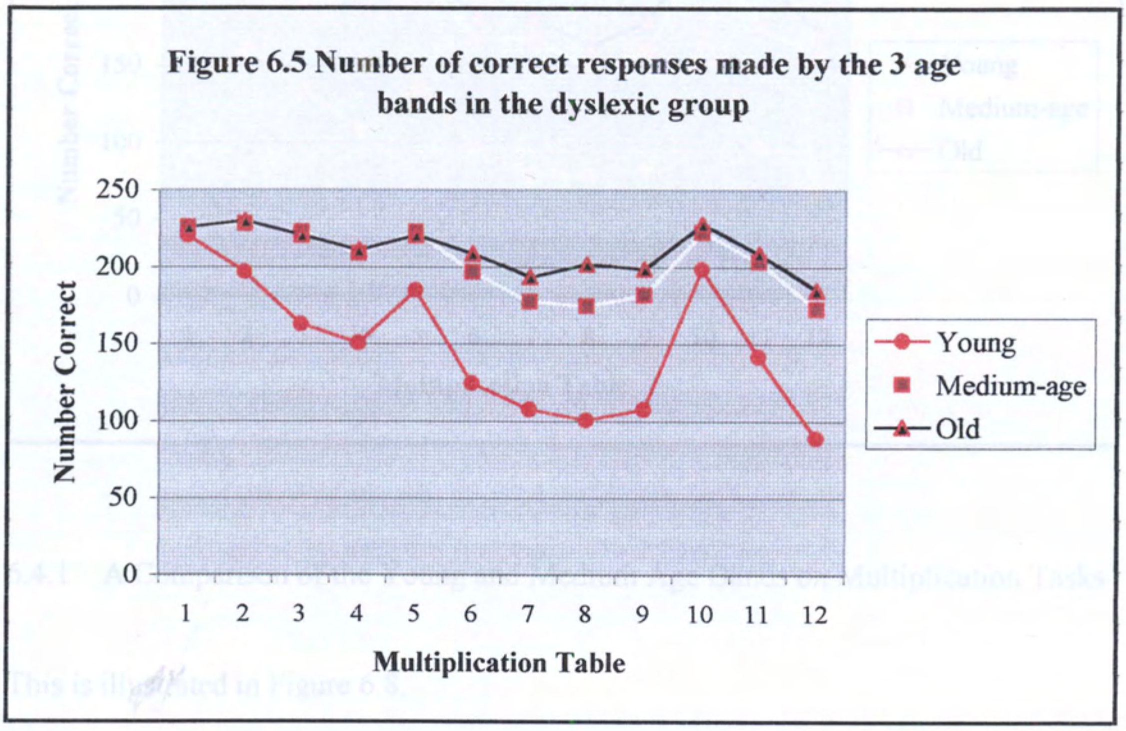


A Chi-squared was performed for the three groups in the old age band. There was no significant difference.

Chi-squared = 11.898, df = 22, ns.

6.4 Comparing Age Bands Within the Separate Groups

The comparisons are illustrated in Figures 6.5, 6.6 and 6.7.



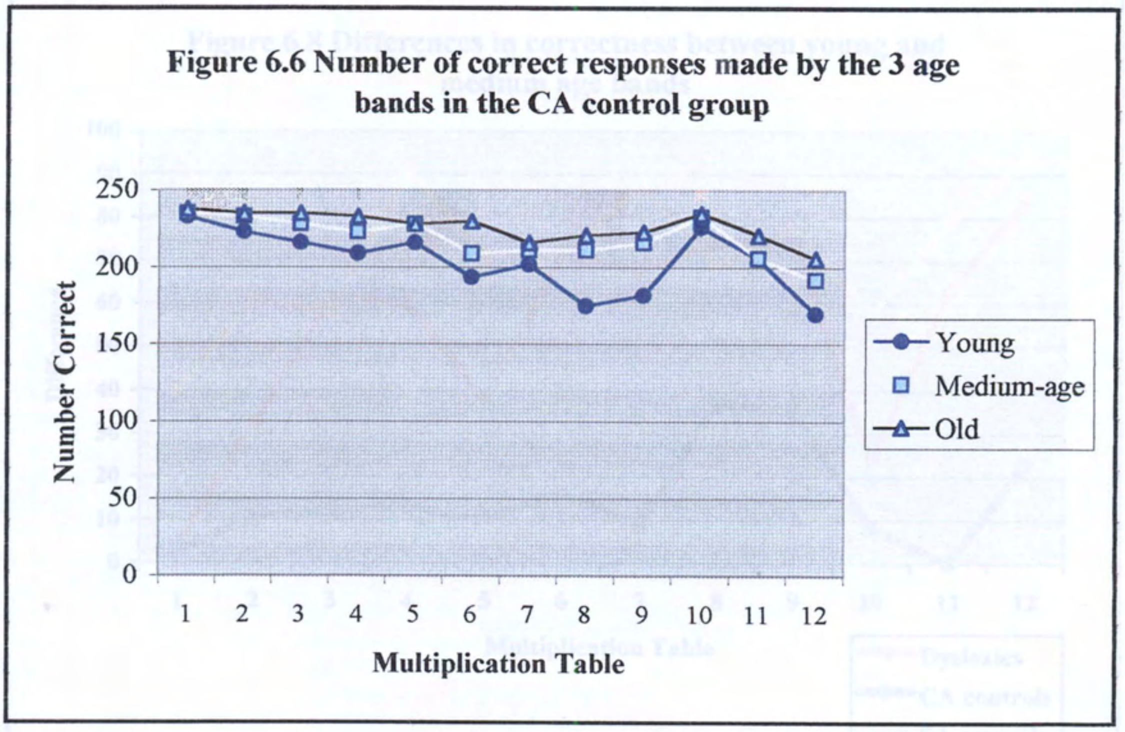
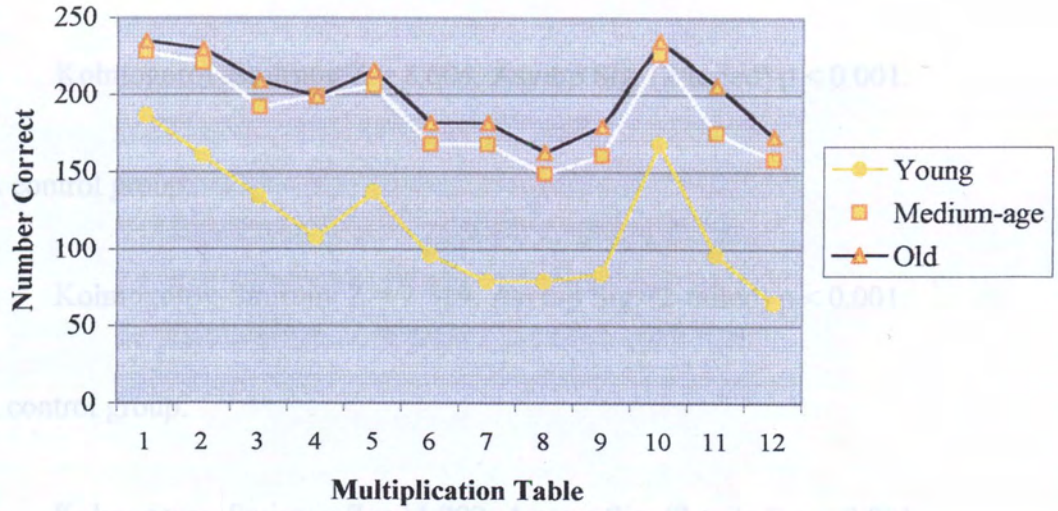


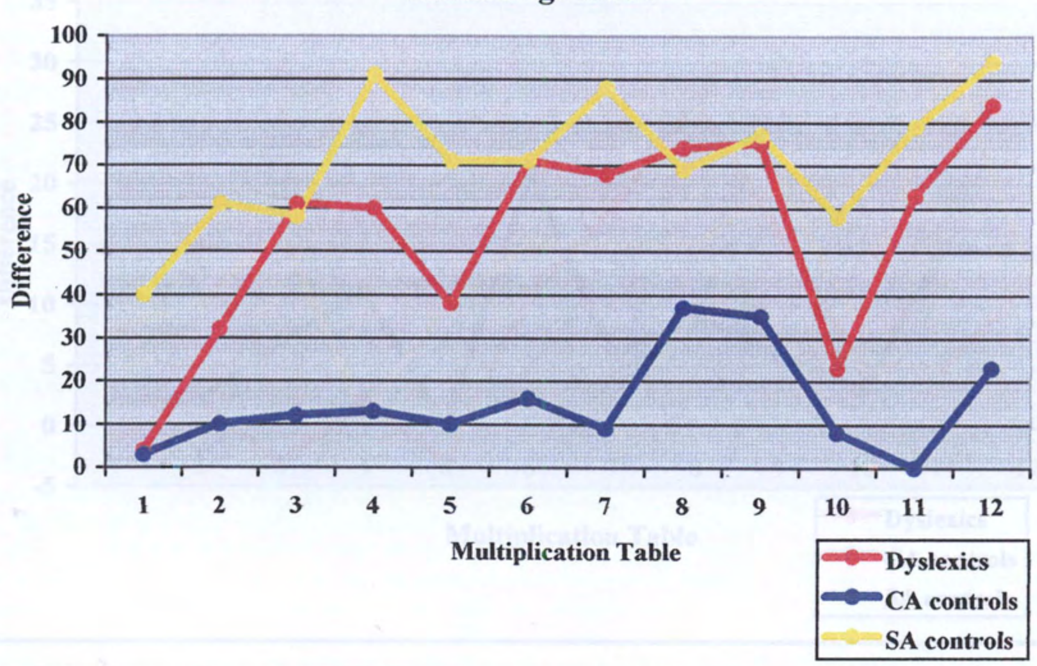
Figure 6.7 Number of correct responses made by the 3 age bands in the SA control group



6.4.1 A Comparison of the Young and Medium Age Bands on Multiplication Tasks

This is illustrated in Figure 6.8.

Figure 6.8 Differences in correctness between young and medium age bands



Two-Sample Kolmogorov-Smirnov Test

Dyslexic group:

Kolmogorov-Smirnov Z = 8.604, Asymp.Sig. (2-tailed) $p < 0.001$.

CA control group:

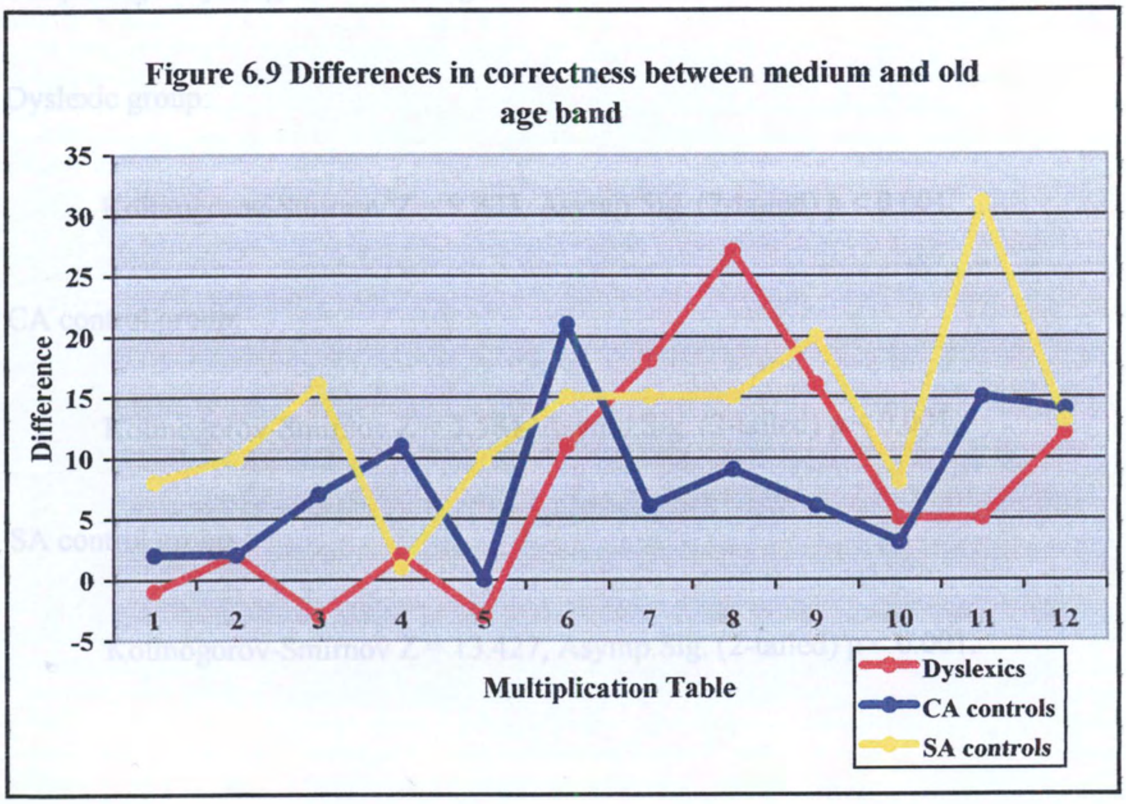
Kolmogorov-Smirnov Z = 2.319, Asymp.Sig. (2-tailed) $p < 0.001$.

SA control group:

Kolmogorov-Smirnov Z = 11.292, Asymp.Sig. (2-tailed) $p < 0.001$.

6.4.2 A Comparison of the Medium and Old Age Band on Multiplication Tasks

This is illustrated in Figure 6.9.



A negative score indicates that the younger group answered more questions correctly than the older group.

Two-Sample Kolmogorov-Smirnov Test

Dyslexic group:

Kolmogorov-Smirnov Z = 1.199, Asymp.Sig. (2-tailed) ns.

CA control group:

Kolmogorov-Smirnov Z = 1.265, Asymp.Sig. (2-tailed) ns.

SA control group:

Kolmogorov-Smirnov Z = 2.135, Asymp.Sig. (2-tailed) $p < 0.001$.

Comparing the young and the old age bands

Dyslexic group:

Kolmogorov-Smirnov Z = 9.803, Asymp.Sig. (2-tailed) $p < 0.001$.

CA control group:

Kolmogorov-Smirnov Z = 3.584, Asymp.Sig. (2-tailed) $p < 0.001$.

SA control group:

Kolmogorov-Smirnov Z = 13.427, Asymp.Sig. (2-tailed) $p < 0.001$.

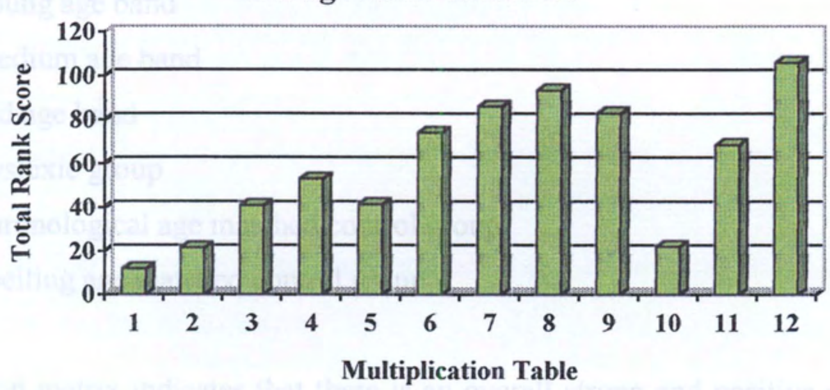
6.5 Order of Difficulty

The results displayed in Tables 6.4, 6.5 and 6.6 show the number of correct responses made by groups and age bands on each multiplication table. Table 6.7 shows the order of difficulty in terms of correctness on multiplication tables for each group and age band found from these Tables. This is also represented in Figure 6.10. The ranking begins with the multiplication table answered most correctly. The ranks have been totalled to give a 'total rank score' and an 'overall rank' found from this. Multiplication table is referred to as 'X table' in Table 6.7.

Table 6.7 Rank order on correct responses for each multiplication table by group and age band

X table	*Dyslexics*			*CA controls*			*SA controls*			*Total rank scores*	*Overall rank*
	Age Band										
	Y	*M*	*O*	*Y*	*M*	*O*	*Y*	*M*	*O*		
1	1	2	3	1	1	1	1	1	1	12	1
2	3	1	1	3	2	2.5	3	3	3	21.5	2
3	5	3	4	5	4	4	5	6	5	41	4
4	6	6	6	6	6	5	6	5	7	53	6
5	4	4.5	5	4	5	7	4	4	4	41.5	5
6	8	8	8	9	10	6	8	8.5	8.5	74	8
7	9	10	11	8	9	11	11	8.5	8.5	86	10
8	11	11	9	11	8	9.5	10	12	12	93.5	11
9	10	9	10	10	7	8	9	10	10	83	9
10	2	4.5	2	2	3	2.5	2	2	2	22	3
11	7	7	7	7	11	9.5	7	7	6	68.5	7
12	12	12	12	12	12	12	12	11	11	106	12

Figure 6.10 Multiplication table total rank scores for all groups and age bands combined



The order of difficulty in terms of correctness for multiplication is:

1×, 2×, 10×, 3×, 5×, 4×, 11×, 6×, 9×, 7×, 8×, 12×

Using the formula for Spearman's rank correlation coefficient (rho) the results shown in Table 6.8 were found:

Table 6.8 Non-parametric correlations using Spearman's rho on order of difficulty on accuracy in multiplication

	MD	*OD*	*YCA*	*MCA*	*OCA*	*YSA*	*MSA*	*OSA*	*Overall Rank*
YD	**0.9387**	**0.9371**	**0.9930**	**0.8531**	**0.8877**	**0.9790**	**0.9842**	**0.9842**	**0.9790**
MD		**0.9492**	**0.9247**	**0.8616**	**0.8946**	**0.9387**	**0.9053**	**0.9193**	**0.9807**
OD			**0.9161**	**0.8601**	**0.9088**	**0.9580**	**0.8932**	**0.9002**	**0.9580**
YCA				**0.8601**	**0.8526**	**0.9580**	**0.9842**	**0.9842**	**0.9650**
MCA					**0.8912**	**0.8741**	***0.8161***	***0.7951***	**0.8811**
OCA						**0.9193**	**0.8471**	**0.8225**	**0.9298**
YSA							**0.9492**	**0.9492**	**0.9790**
MSA								**0.9789**	**0.9527**
OSA									**0.9597**

Key:

Results in **bold** show a correlation that is significant at the 0.001 level (2-tailed).

Results in ***bold italic*** show a correlation that is significant at the 0.01 level (2-tailed).

Y = young age band

M = medium age band

O = old age band

D = dyslexic group

CA = chronological age matched control group

SA = spelling age matched control group

A correlation matrix indicates that there is an overall strong and positive correlation between the orders of difficulty irrespective of group and age band.

6.6 Special Number Combinations in Multiplication

Are there any special number combinations for multiplication that are more likely than others to generate errors?

Are dyslexics making extra use of algorithms because of their difficulty in retrieving from memory? If this is so, then in the case of products that do not have any obvious algorithm, are dyslexics weaker at producing correct responses than the CA controls and SA controls?

From the multiplication tasks already presented to the participants, two types of questions were selected. Firstly, a study of the 'order of difficulty' in section 6.5 showed that several of the multiplication tables ranked 1 to 7 in the overall rankings (answered the most correctly) had well known patterns or obvious algorithms. From these, sums from the 10 and 11 multiplication tables were selected and called 'XM-type' questions. The 'M' denotes the operation of multiplication.

The second type of question chosen for comparison came from the multiplication tables ranked 8 to 12 in the overall rankings. Questions were chosen from the 7 and 8 multiplication tables since they had no clear algorithms for the participants to employ. These were called 'YM-type' questions. The 'M' denotes the operation of multiplication.

Selection of questions was based on the following:

(1) No multiplier or multiplicand less than 6 on the basis of the question being too easy.

(2) No product over 100 on the basis of the question being too hard.

The sums that were selected therefore included 7, 8, 10 and 11 as the multiplicands and 6, 7, 8 and 9 as the multipliers.

The 'X_M-type' sums were: $10 \times 6, 10 \times 7, 10 \times 8, 10 \times 9$

$11 \times 6, 11 \times 7, 11 \times 8, 11 \times 9$

The 'Y_M-type' sums were: $7 \times 6, 7 \times 7, 7 \times 8, 7 \times 9$

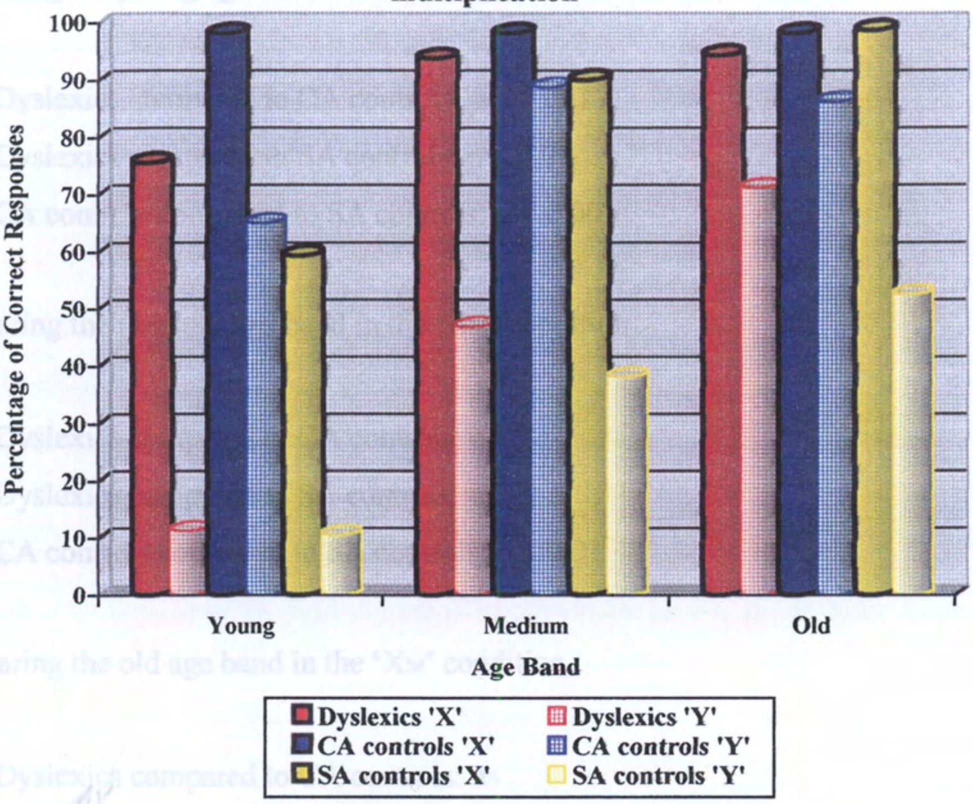
$8 \times 6, 8 \times 7, 8 \times 8, 8 \times 9$

Each sum was presented twice to each participant and thus there were results for 16 'X_M-type' and 16 'Y_M-type' sums. Table 6.9 shows the number of correct responses made by each group/age-band on the 'X_M' and 'Y_M' type condition. The results are illustrated graphically in Figure 6.11. The maximum number of correct responses is 160.

Table 6.9 Percentage of correct responses for the three groups and the three age bands in the 'X_M' condition and 'Y_M' condition for multiplication

	'X_M' condition	*'Y_M' condition*
Young age band		
Dyslexics	75.63	11.25
CA controls	98.13	65.00
SA controls	59.38	10.53
Medium age band		
Dyslexics	93.75	46.88
CA controls	98.13	88.75
SA controls	90.00	38.13
Old age band		
Dyslexics	94.38	71.25
CA controls	98.13	86.25
SA controls	98.75	52.50

Figure 6.11 Percentage of correct responses for the 3 groups and the 3 age-bands in the 'X$_M$' and 'Y$_M$' conditions for multiplication



In Figure 6.11:

- the 'X$_M$' condition is represented by dark orange (dyslexics) and dark blue (CA controls) and yellow (SA controls);
- the 'Y$_M$' condition is represented by pale orange (dyslexics) and pale blue (CA controls) and pale yellow (SA controls).

Analysis of variance results (between-subjects effects) showed:

- Comparing the young in the 'X$_M$' condition $F(2,477) = 40.684$, $p < 0.001$
- Comparing the medium-age in the 'X$_M$' condition $F(2,477) = 4.724$, $p < 0.01$
- Comparing the old in the 'X$_M$' condition $F(2,477) = 3.186$, $p < 0.05$

Post hoc (Tamhane) tests showed:

Comparing the young age band in the 'XM' condition:

- Dyslexics compared to CA controls: $p < 0.001$
- Dyslexics compared to SA controls: $p < 0.01$
- CA controls compared to SA controls: $p < 0.001$

Comparing the medium age band in the 'XM' condition

- Dyslexics compared to CA controls: ns
- Dyslexics compared to SA controls: ns
- CA controls compared to SA controls: $p < 0.01$

Comparing the old age band in the 'XM' condition

- Dyslexics compared to CA controls: ns
- Dyslexics compared to SA controls: ns
- CA controls compared to SA controls: ns

Analysis of variance results (between-subjects effects) showed:

- Comparing the young in the 'YM' condition $F(2,477) = 110.054$, $p < 0.001$
- Comparing the medium-age in the 'YM' condition $F(2,477) = 45.036$, $p < 0.001$
- Comparing the old in the 'YM' condition $F(2,477) = 23.811$, $p < 0.001$

Post hoc (Tamhane) tests showed:

Comparing the young age band in the 'YM' condition

- Dyslexics compared to CA controls: $p < 0.001$
- Dyslexics compared to SA controls: ns
- CA controls compared to SA controls: $p < 0.001$

Comparing the medium age band in the 'Y_M' condition

- Dyslexics compared to CA controls: $p < 0.001$
- Dyslexics compared to SA controls: ns
- CA controls compared to SA controls: $p < 0.001$

Comparing the old age band in the 'Y_M' condition

- Dyslexics compared to CA controls: $p < 0.01$
- Dyslexics compared to SA controls: $p < 0.01$
- CA controls compared to SA controls: $p < 0.001$

Young dyslexics performed *differentially* better on the 'X_M' condition compared with the 'Y_M' condition than the SA controls (Chi-squared = 10.70, $p < 0.005$).

6.7 Chapter Summary – Questions Answered

At the start of the chapter three questions were raised. The first of these was *whether dyslexics make fewer correct responses than non-dyslexics when performing multiplication?* The answer to this question is both 'yes' and 'no'.

Taking firstly the experimental groups with age bands combined, a study of the mean proportion of multiplication questions that were answered correctly showed that the dyslexics made more correct responses than the SA controls, but were not as accurate as the CA controls. All groups and age bands were significantly different from one another ($p < 0.001$) except for non-significant findings between the medium-age and old age band and also the dyslexics and SA controls on post hoc tests. There was a significant interaction between age and group ($p < 0.008$). The standard deviation (in Table 6.1) was greater for the dyslexics than the CA controls indicating that there was greater variability between their responses.

An analysis of variance on group, age band and intercept of group and age band for each of the twelve multiplication tables gave a 'p' value of 0.001 in each case. Post hoc tests on each of the multiplication tables showed that the dyslexics were significantly less accurate than the CA controls ($p < 0.001$) for each table, and likewise the CA controls were significantly more accurate than the SA controls ($p < 0.001$) on each table. No significant differences were found between the dyslexics and SA controls on the 1× and 10× tables, otherwise differences in the dyslexics' favour were found between these two groups ranging from $p < 0.05$ to $p < 0.001$.

Non-parametric correlations using Spearman's rho on the order of difficulty showed that there was an overall strong and positive correlation between the order irrespective of group and age band. Thus for both dyslexics and non-dyslexics the combined order of difficulty was 1×, 2×, 10×, 3×, 5×, 4×, 11×, 6×, 9×, 7×, 8×, 12×. Thus where a table was difficult in terms of accuracy for one participant, whether dyslexic or not, it was likely to be difficult for others.

The effect of age on dyslexics compared to non-dyslexics is considered as part of the answer to the next question.

Secondly, it was asked *whether younger dyslexics make fewer correct responses than older dyslexics when performing multiplication.* The answer to this question is 'yes'.

A significant difference ($p < 0.001$) was found between the age bands on all multiplication tables. Post hoc tests showed that the greatest differences ($p < 0.001$) in all cases occurred between the young and medium-age, and young compared to old age bands. Non-significant results were found between the medium-age and old age bands for the 1×, 2×, 3×, 4×, 5× and 10× tables.

A Chi-squared test showed that there was a significant difference ($p < 0.001$) between the three groups over the twelve multiplication tables in the young age band but not so between the groups in the medium-age (ns) and old age bands (ns).

In the young age band the CA controls performed more accurately on all tables than the dyslexics, who likewise performed more accurately than the SA controls. While the SA controls were less accurate than the dyslexics, the pattern of accuracy over the twelve tables 'shadowed' that of the dyslexics (see Figure 6.2). The CA controls performed with less variability than the two other groups over the twelve tables in each age band.

A comparison between the young and medium age bands was significant ($p < 0.001$) for all the groups using the Kolmogorov-Smirnov test (in section 6.4.1). The difference between these two age bands was least in the case of the CA controls and greatest for the SA controls with the dyslexic results lying in between these two groups (see Figure 6.8).

Comparing the performance of the medium-age and old age bands, there were no significant differences for both the dyslexics and the CA controls while the old SA controls performed significantly better than the medium-age SA controls ($p < 0.001$).

Thirdly, it was asked *if there are any special number combinations that are more likely than others to generate errors?* The answer to this question is 'yes'.

The lowest number of correct responses by the young CA controls was on the 12× table (170 correct out of a maximum of 240 responses). In comparison the young dyslexics made 89 correct responses for the 12×. Indeed they exceeded 170 correct responses on only the 1×, 10×, 2× and 5× tables (see Table 6.4).

In the medium age band the CA controls responded more correctly on all tables than the dyslexics with the greatest gap between these two groups on the 7×, 8×, 9× and 12× tables.

The medium-age SA controls made more correct responses than the medium-age dyslexics on the 1× (one more) and the 10× (3 more) tables. This was also found in the old age band on the 1x (10 more), 2x (1 more) and 10x (6 more) tables. Thus the medium-age dyslexics (mean age 12 years 7 months) were performing at approximately the same level as non-dyslexics with a mean age of 8 years 9 months.

In the old age band the dyslexics 'shadowed' the performance of the CA controls, but were less accurate (in Figure 6.4).

On all age bands and for all groups greater accuracy was found on the 1×, 2×, 5× and 10× tables. When comparing the young and medium-age dyslexics least change in accuracy was found on the 1×, 2×, 5× and 10× tables than the other tables. Neither the CA nor SA controls showed this pattern on this age comparison. The medium-age dyslexics were more accurate than the old dyslexics on the 1× (1 more), 3× (3 more) and 5× (3 more) tables. No such cases of younger participants outperforming older participants were found in the non-dyslexic results.

A question raised by the data was whether dyslexics were making extra use of algorithms, because of their difficulty in retrieving from memory. If so, then in the case of products where there is no obvious algorithm, it would be expected that the SA controls would perform relatively better than the dyslexics on accuracy (and speed – see Chapter 10).

To test this prediction two types of multiplication sum were chosen that represented those tables with obvious algorithms ('X_M' condition) and those without ('Y_M' condition). The reasoning behind the selection of these is detailed in section 6.6. Thus the 'X_M' condition contained 8 sums from the 10× and 11× tables with 10 and 11 as the multiplicands and 6, 7, 8 and 9 as the multipliers. The 'Y_M' condition contained 8 sums from the 7× and 8× tables with 7 and 8 as the multiplicands and 6, 7, 8 and 9 as the multipliers. These were presented in two trials.

The results given in Table 6.9 show the percentage of correct responses for the three groups and three age bands in the 'X_M' and 'Y_M' conditions. All groups and age bands made more correct responses on the 'X_M' condition than the 'Y_M' condition.

On the 'X_M' condition greater variability of response between the groups was found in the young age band ($p < 0.001$) than the medium age band ($p < 0.01$) with the least variability found in the old age band ($p < 0.05$). Except in the old 'X_M' condition, the order of correctness among the groups was CA controls and then dyslexics with the SA controls being the least correct. The closest results are given in the 'Y_M' condition between the young dyslexics and the young SA controls. The young dyslexics (mean age of 10 years 7 months) gave 11.25% correct responses (18 out of 160) in the 'Y_M' condition compared with 10.53% (17 out of 160) by the young SA controls, whose mean age was 7 years 8 months. Thus the young dyslexics were performing with the same level of accuracy as non-dyslexics whose mean age was almost three years less (see Chapter 3, Table 3.2).

Comparing this weak performance of the young dyslexics with their stronger performance over the SA controls on the 'XM' condition it was found that the young dyslexics were differentially better on the 'XM' condition compared with the 'YM' condition than the SA controls (121 correct responses in the 'XM' condition compared with 18 in the 'YM' condition, as against 95 compared with 17 by the SA controls) ($p < 0.001$).

The dyslexics were not significantly different from non-dyslexics in the medium-age and old age bands on the 'XM' condition.

The dyslexics in each age band on the 'YM' condition performed significantly worse than the CA controls (young $p < 0.001$, medium-age $p < 0.001$, old $p < 0.01$). Compared to the SA controls the dyslexics were not significantly different in the young or medium age bands but they performed better than the SA controls in the old age band ($p < 0.01$).

Thus on products selected because they require memorisation the dyslexics' performance on accuracy was adversely affected.

CHAPTER 7

Correctness on Division Tasks

7.1 Aims of This Chapter
7.2 Overall Comparisons
7.3 Tasks Within Division
7.4 Comparing Age Bands Within the Separate Groups
7.5 Order of Difficulty
7.6 Special Number Combinations in Division
7.7 Chapter Summary – Questions Answered

7.1 Aims of This Chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of division:

(1) Do dyslexics make fewer correct responses than non-dyslexics?

(2) Do younger dyslexics make fewer correct responses than older dyslexics?

(3) Are there any special number combinations that are more likely than others to generate errors?

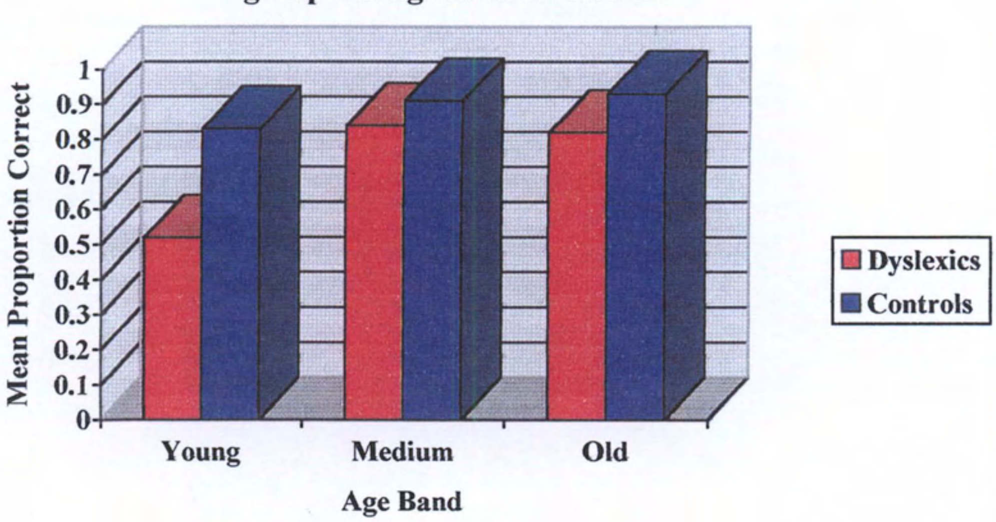
7.2 Overall Comparisons

The mean proportion of correct responses for each group and age band is reported in Table 7.1 and Figure 7.1.

Table 7.1 Mean proportion of correct responses for each age band and group on division

Age	*Group*	*Mean proportion correct*	*Standard deviation*
Young	Dyslexics	0.52	0.23
	Controls	0.83	0.09
Medium	Dyslexics	0.84	0.09
	Controls	0.91	0.08
Old	Dyslexics	0.82	0.13
	Controls	0.93	0.04

Figure 7.1 Mean proportion of correct responses for each group and age band on division



Analysis of variance shows the following overall results:

- An age effect ($F(2, 54) = 16.930$, $p < 0.001$).
- A group effect ($F(1, 54) = 25.538$, $p < 0.001$).
- An age and group effect ($F(2, 54) = 5.536$, $p < 0.01$).

Analysis of variance tables are presented in Appendix F2.

Post hoc testing (Tamhane) showed:

- Young compared to medium-age, and young compared to old age band: $p < 0.01$.
- No significant difference between the medium-age and old age band.

t-Tests results comparing the groups in each age band showed:

- Young ($t = 3.991$, $df = 18$, $p < 0.001$).
- Medium-age ($t = 1.799$, $df = 18$, ns).
- Old ($t = 2.546$, $df = 18$, $p < 0.05$).

7.3 Tasks Within Division

A summary of the analysis of variance is shown in Table 7.2 with post hoc tests presented in Table 7.3.

Table 7.2 Analysis of variance (between-subjects effects) showing the F values and significant differences in mean response times between groups, age bands and intercept of groups and age bands

Division table	*Group*	*Age band*	*Group and age band*
1	1.745	5.203**	1.54
2	14.313***	5.760**	6.071**
3	12.205***	8.400***	3.552*
4	14.438***	14.356***	6.882**
5	21.992***	8.729***	4.128*
6	15.863***	11.816***	3.094
7	25.173***	11.235***	1.396
8	22.154***	17.517***	1.936
9	25.236***	15.302***	4.350*
10	6.377*	3.343*	1.541
11	5.301*	7.509***	1.689
12	22.065***	12.018***	5.357**
	F (2,54)	F (2, 54)	F (4, 54)

Significance levels key for Tables 7.2 and 7.3:

*** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

Table 7.3 Post hoc tests (Tamhane)

Division table	*Age band comparisons*		
	Y/M	*Y/O*	*M/O*
1	ns	ns	ns
2	ns	ns	ns
3	*	*	ns
4	**	*	ns
5	ns	*	ns
6	*	**	ns
7	*	**	ns
8	***	***	ns
9	**	**	ns
10	ns	ns	ns
11	**	ns	ns
12	**	*	ns

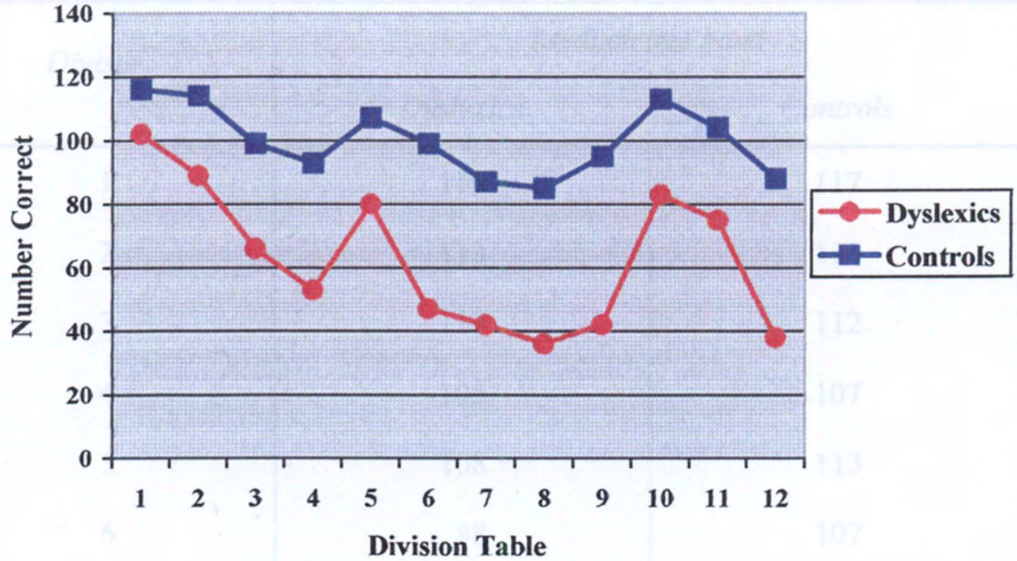
Key: Y (young), M (medium), O (old).

Since there were 12 questions and 10 subjects, the maximum possible number of correct responses was 120 for each division table.

Table 7.4 Number of correct responses made by the dyslexics and non-dyslexics in the young age band, broken down by table

Divisor	*Young age band*	
	Dyslexics	*Controls*
1	102	116
2	89	114
3	66	99
4	53	93
5	80	107
6	47	99
7	42	87
8	36	85
9	42	95
10	83	113
11	75	104
12	38	88

Figure 7.2 Number of correct responses by the two groups in the young age band



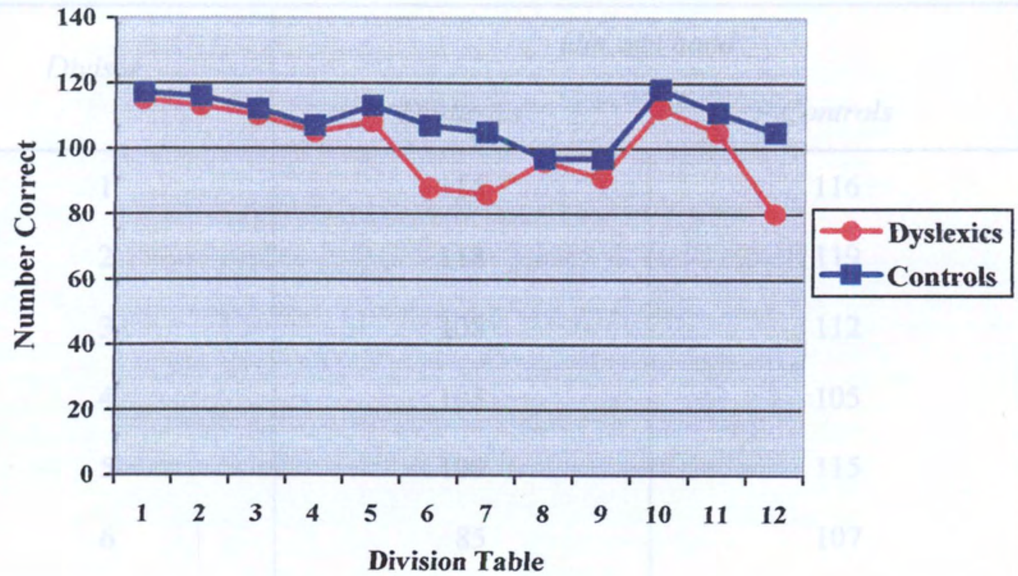
Chi-squared = 28.306, df = 11, $p < 0.01$. The performance of the dyslexics is different on the number of correct answers on division compared to the controls. The young dyslexics significantly under-perform the controls on all tables.

These results show that the tables producing the largest number of incorrect responses were the 6, 7, 8, 9 and 12 division tables.

Table 7.5 Number of correct responses made by the dyslexics and non-dyslexics in the medium age band, broken down by table

Divisor	*Medium age band*	
	Dyslexics	*Controls*
1	115	117
2	113	116
3	110	112
4	105	107
5	108	113
6	88	107
7	86	105
8	96	97
9	91	97
10	112	118
11	105	111
12	80	105

Figure 7.3 Number of correct responses by the two groups in the medium age band

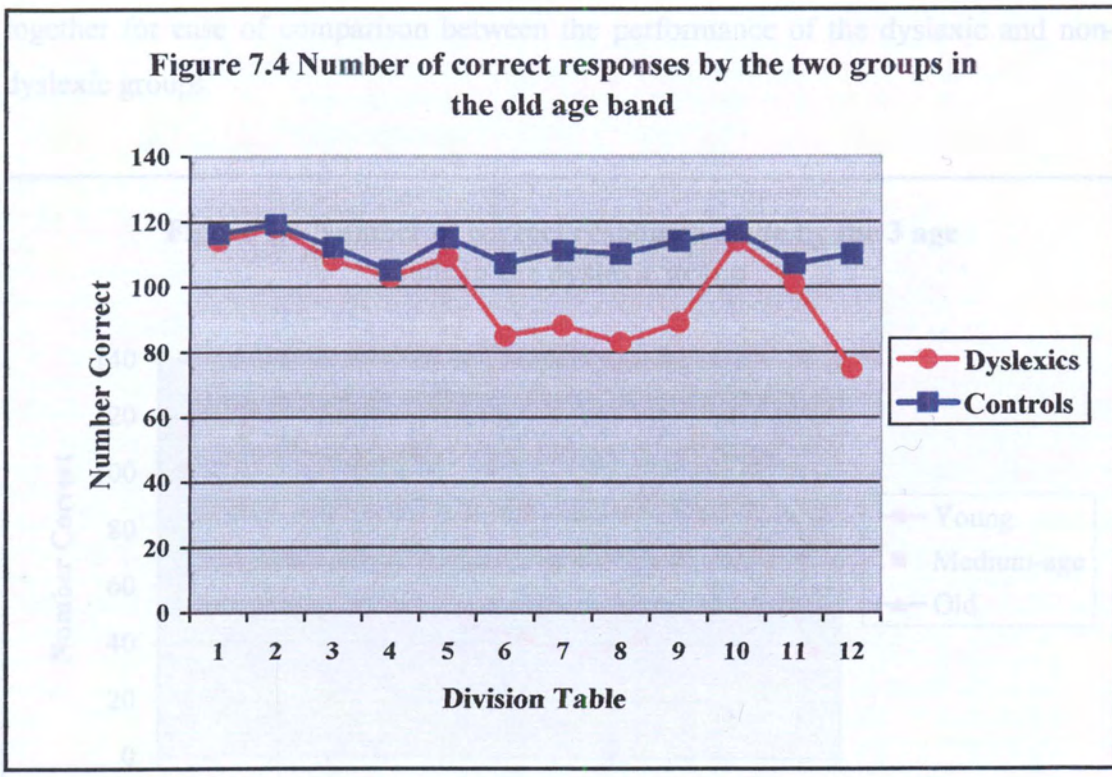


Chi-squared = 4.186, df = 11, ns. The performance of the dyslexics and controls are significantly similar across all tables.

These results show that the tables producing the largest number of incorrect responses were the 6, 7, 8, 9 and 12 division tables.

Table 7.6 Number of correct responses made by the dyslexics and non-dyslexics in the old age band, broken down by table

Divisor	*Old age band*	
	Dyslexics	*Controls*
1	114	116
2	118	119
3	108	112
4	103	105
5	109	115
6	85	107
7	88	111
8	83	110
9	89	114
10	114	117
11	101	107
12	75	110



Chi-squared = 9.560, df = 11, ns. The performance of the dyslexics and controls are significantly similar across all tables.

The results show that the tables producing the largest number of incorrect responses were the 6, 7, 8, 9 and 12 division tables. The least difference between the dyslexics and non-dyslexics was on the 2-division table.

7.4 Comparing Age Bands Within the Separate Groups

How well do the young dyslexics perform in comparison to the medium-age dyslexics? Are the findings similar when comparing the performance of the medium-age dyslexics to the old dyslexics? Is there a comparable difference for the non-dyslexics?

The number of correct responses per division table is recorded in Figure 7.5 for each of the dyslexic age bands. Figure 7.6 gives the results for each of the control age bands. The maximum number of possible correct responses per division table is 120 (10 participants × 12 questions per division table). Both figures have been placed together for ease of comparison between the performance of the dyslexic and non-dyslexic groups.

Figure 7.5 Number of correct responses made by the 3 age bands in the dyslexic group

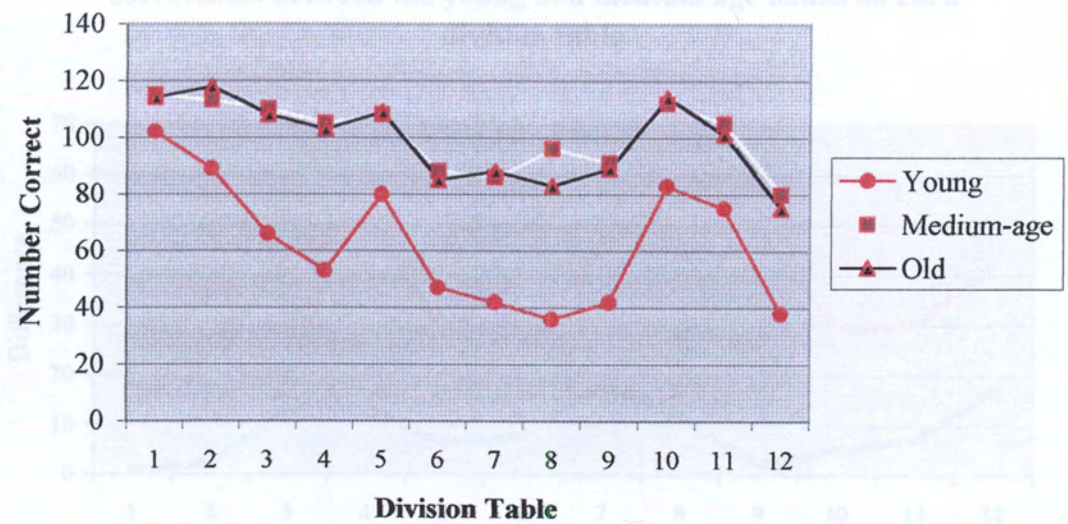
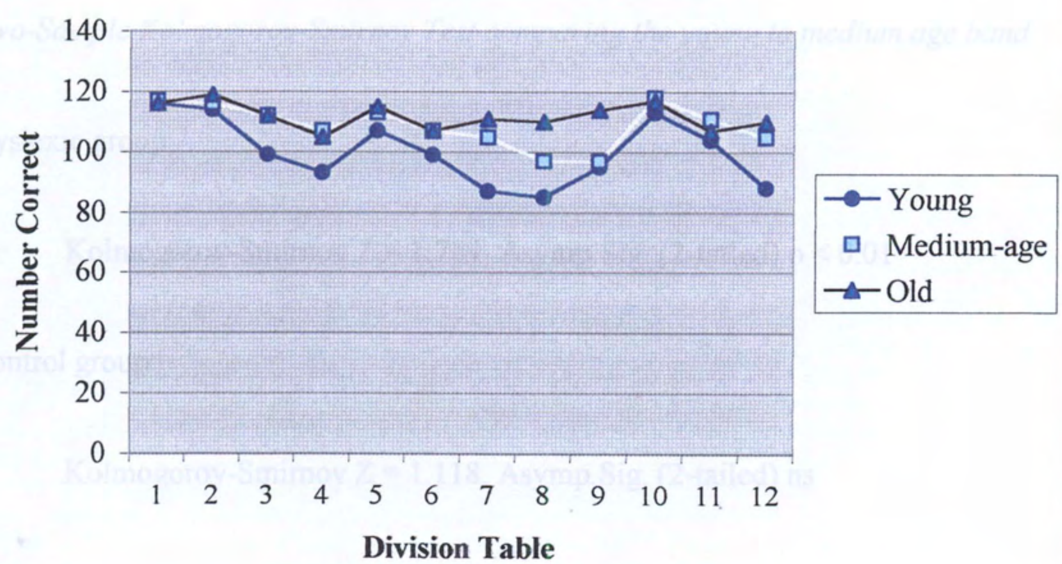


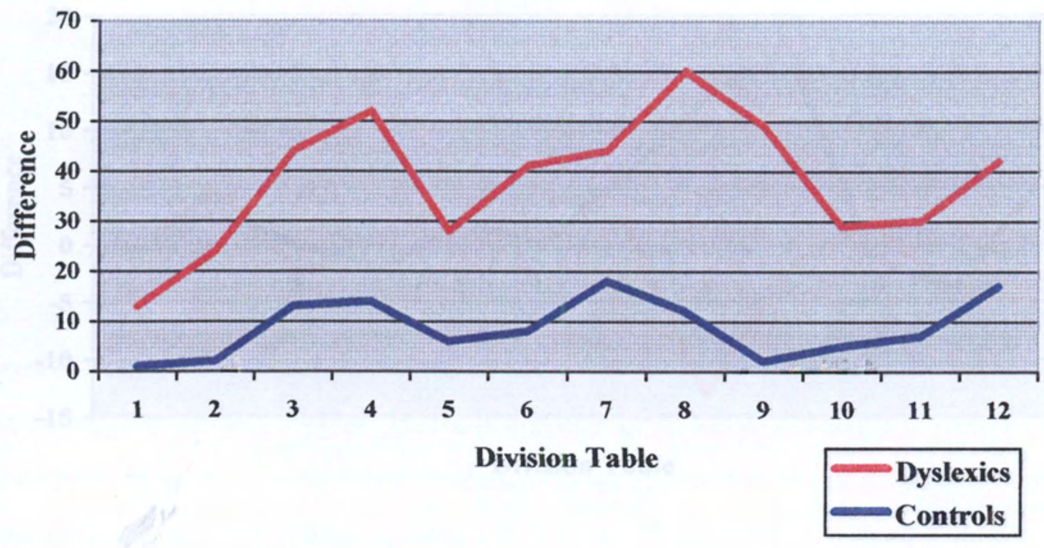
Figure 7.6 Number of correct responses made by the 3 age bands in the control group



7.4.1 A Comparison of the Young and Medium Age Bands on Division Tasks

This is illustrated in Figure 7.7.

Figure 7.7 Group comparison showing the difference in correctness between the young and medium age bands on each division table



Two-Sample Kolmogorov-Smirnov Test comparing the young to medium age band

Dyslexic group:

Kolmogorov-Smirnov Z = 1.789, Asymp.Sig. (2-tailed) $p < 0.01$

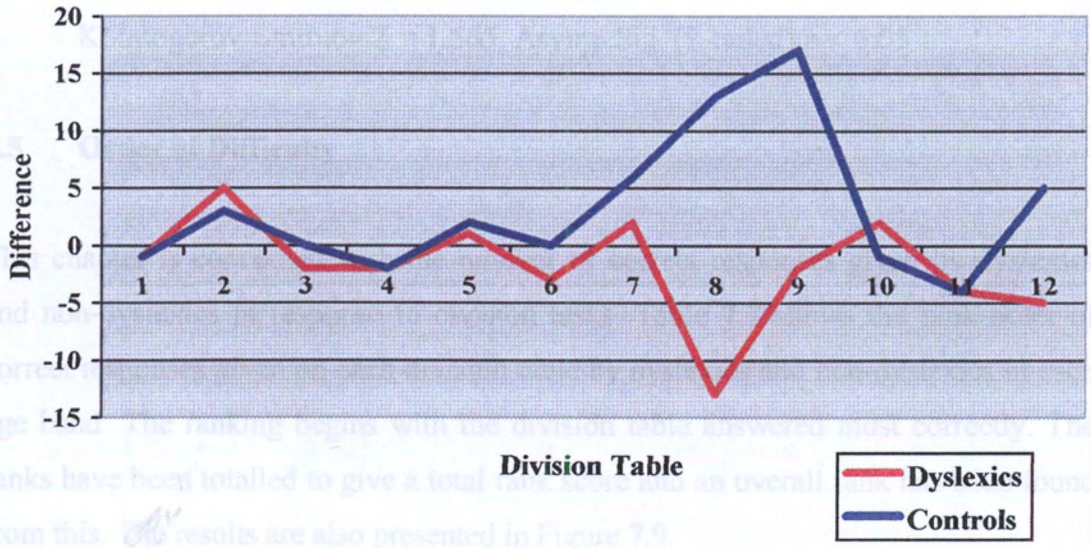
Control group:

Kolmogorov-Smirnov Z = 1.118, Asymp.Sig. (2-tailed) ns

7.4.2 A Comparison of the Medium and Old Age Bands on Division Tasks

This is illustrated in Figure 7.8.

Figure 7.8 Group comparison showing the difference in correctness between the medium and old age band on each division table



Two-Sample Kolmogorov-Smirnov Test comparing the medium to the old age band

Dyslexic group:

Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns

Control group:

Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns

Two-Sample Kolmogorov-Smirnov Test comparing the young to the old age band

Dyslexic group:

Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$

Control group:

Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$

7.5 Order of Difficulty

This chapter is concerned with the number of correct responses given by dyslexics and non-dyslexics in response to division tasks. Table 7.7 shows the rank order of correct responses given on each division table by dyslexics and non-dyslexics in each age band. The ranking begins with the division table answered most correctly. The ranks have been totalled to give a total rank score and an overall rank has been found from this. The results are also presented in Figure 7.9.

Table 7.7 Rank order on correct responses for each division table by group and age band

Division table	*Dyslexics*			*Controls*			*Total rank scores*	*Overall rank*
	Age bands							
	Y	*M*	*O*	*Y*	*M*	*O*		
1	1	1	2.5	1	1.5	3	10	1
2	2	2	1	2	3	1	11	2
3	6	4	5	6.5	5.5	6.5	33.5	5
4	7	6.5	6	9	7.5	12	48	7
5	4	5	4	4	4	4	25	4
6	8	10	10	6.5	7.5	10.5	52.5	9
7	9.5	11	9	10.5	9.5	6.5	56	10
8	12	8	11	12	11.5	8.5	63	11
9	9.5	9	8	8	11.5	5	51	8
10	3	3	2.5	3	1.5	2	15	3
11	5	6.5	7	5	5.5	10.5	39.5	6
12	11	12	12	10.5	9.5	8.5	63.5	12

Figure 7.9 Division table total rank scores for all groups and age bands combined

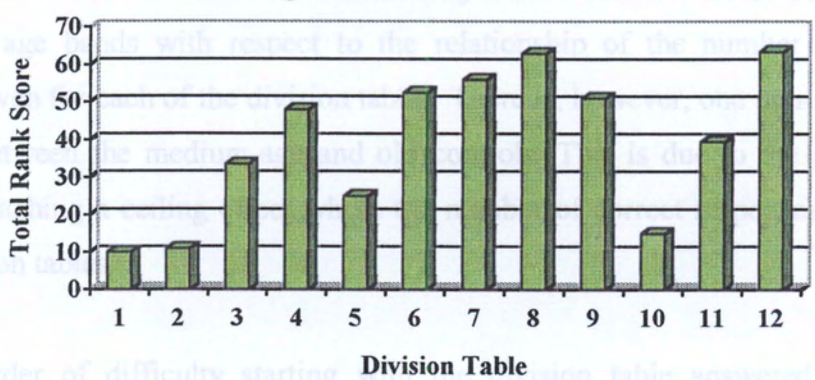


Table 7.8 shows the correlation, using Spearman's rho, between the rankings for division tables between each of the group age bands, as found in Table 7.7.

Table 7.8 Spearman's rho on division table rankings between the group age bands

		Dyslexics			*Controls*			*Overall rank*
		Young	*Medium-age*	*Old*	*Young*	*Medium-age*	*Old*	
Dyslexics	Young		0.891**	0.937**	0.965**	0.961**	0.593*	0.974**
	Medium-age			0.930**	0.833**	0.852**	0.618*	0.949**
	Old				0.872**	0.873**	0.701*	0.974**
Controls	Young					0.920**	0.638*	0.940**
	Medium-age						ns	0.910**
	Old							0.664*

Significance levels key for Table 7.8:

** $p < 0.01$

* $p < 0.05$

Using Spearman's rho, in nearly all the groups and age bands the order of the division tables is significantly positively correlated (* $p < 0.05$, ** $p < 0.01$). Thus there are no significant differences in the order of difficulty of the division tables between the groups and age bands with respect to the relationship of the number of correct responses given for each of the division tables. There is, however, one non-significant finding – between the medium-age and old controls. This is due to the participant responses reaching a ceiling effect where the number of correct responses was high for all division tables.

Thus the order of difficulty starting with the division table answered the most correctly is: 1, 2, 10, 5, 3, 11, 4, 9, 6, 7, 8 and 12.

7.6 Special Number Combinations in Division

Are there any special number combinations for division that are more likely than others to generate errors?

Are dyslexics making extra use of algorithms because of their difficulty in retrieving from memory? If this is so, then in the case of division facts that do not have any obvious algorithm, are dyslexics weaker at producing correct responses than the controls?

From the division tasks already presented to the participants, two types of questions were selected. Firstly, a study of the 'order of difficulty' in section 7.5 showed that several of the division tables in the top half of the overall rankings (answered the most correctly) had well known patterns or obvious algorithms. From these, sums from the 10 division and 11 division tables were selected. These were called 'X_D-type' questions. The 'D' denotes the operation of division.

The second type of question chosen for comparison came from the bottom half of the overall rankings. From these, sums were chosen from the 7 division and 8 division tables since they had no clear algorithms for the participants to employ. These were called 'Y_D-type' questions.

Selection of questions was based on the following:

(1) No divisor or quotient less than 6 on the basis of the question being too easy. An item is 'easy' if many of the participants answer it correctly.

(2) No dividend over 100 on the basis of the question being too hard.

The division sums that were selected therefore included 7, 8, 10 and 11 as the divisor and 6, 7, 8 and 9 as the quotient.

The 'X_D -type' sums were: $60 \div 10, 70 \div 10, 80 \div 10, 90 \div 10$

$66 \div 11, 77 \div 11, 88 \div 11, 99 \div 11$

The 'Y_D -type' sums were: $42 \div 7, 49 \div 7, 56 \div 7, 63 \div 7$

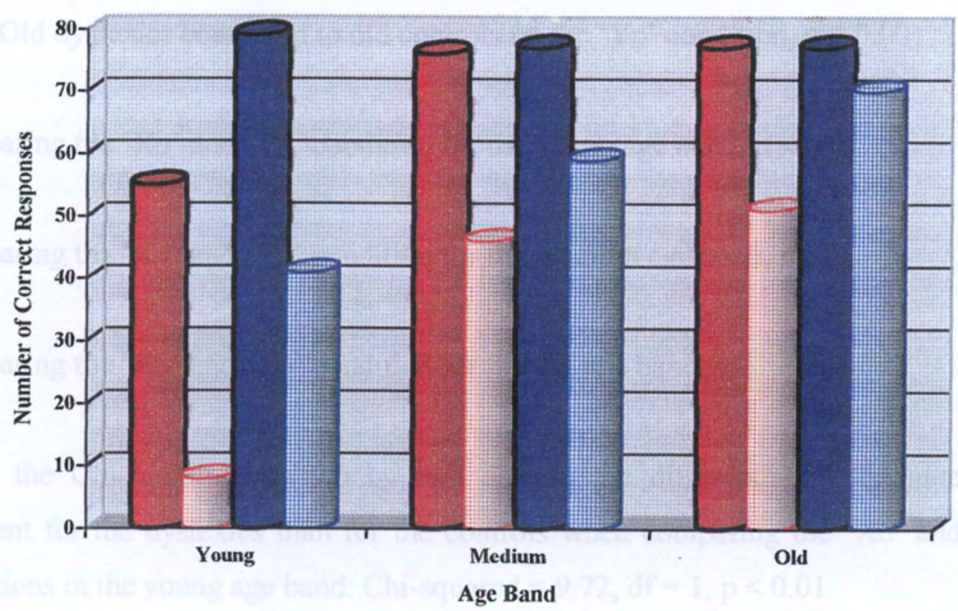
$48 \div 8, 56 \div 8, 64 \div 8, 72 \div 8$

Since each division sum had been presented once to each participant there were results for 8 'X_D -type' and 8 'Y_D -type' division sums per participant. Table 7.9 shows the number of correct responses out of a total of 80 (8 questions × 10 participants), made by each group/age-band on the 'X_D' or the 'Y_D' type condition.

Table 7.9 Number of correct responses for the two groups/age-bands in the 'X_D' condition and 'Y_D' condition for division

Groups and age bands	*'X_D' condition*	*'Y_D' condition*
Young age band		
Dyslexics	55	8
Controls	79	41
Medium age band		
Dyslexics	76	46
Controls	77	59
Old age band		
Dyslexics	77	51
Controls	77	70

Figure 7.10 Number of correct responses by the 3 groups and 3 age bands on the 'X_D' and 'Y_D' conditions for division



Maximum number of correct responses is 80.

Using Fisher's Exact Test, a comparison was made of the two experimental groups in the 'XD' and 'YD' conditions.

The 'XD' condition is represented by dark orange (dyslexics) and dark blue (controls) in Figure 7.10.

- Young dyslexics compared to young controls on the 'XD' condition, $p < 0.001$.
- Medium-age dyslexics compared to medium-age controls on the 'XD' condition, ns.
- Old dyslexics compared to old controls on the 'XD' condition, ns.

The 'YD' condition is represented by pale orange (dyslexics) and pale blue (controls) in Figure 7.10.

- Young dyslexics compared to young controls on the 'YD' condition, $p < 0.001$.
- Medium-age dyslexics compared to medium-age controls on the 'YD' condition, $p < 0.05$.
- Old dyslexics compared to old controls on the 'YD' condition, $p < 0.001$.

Comparing the 'XD' and 'YD' condition for the young age band, $p < 0.01$.

Comparing the 'XD' and 'YD' condition for the medium age band, ns.

Comparing the 'XD' and 'YD' condition for the old age band, ns.

Using the Chi-square test (two by two design) the differential is fundamentally different for the dyslexics than for the controls when comparing the 'XD' and 'YD' conditions in the young age band: Chi-squared = 9.72, df = 1, $p < 0.01$.

7.7 Chapter Summary – Questions Answered

A '÷' before a number represents a particular division table.

Question 1: *Do dyslexics make fewer correct responses than non-dyslexics?*

The answer to this question is 'yes'.

An analysis of variance on the mean proportion of correct responses showed that the dyslexics overall performed significantly less accurately than the controls overall on division ($p < 0.001$).

Next a study was made of the two groups on each of the 12 division tables. The controls were again significantly more accurate than the dyslexics on all tables at $p < 0.001$ except ÷10 and ÷11 ($p < 0.05$) and not at all on ÷1.

While dyslexics were less accurate than the controls, non-parametric correlations using Spearman's rho on the order of difficulty showed that there was an overall strong and positive correlation between the order of difficulty, irrespective of group and age band, except between the medium-age and old controls (due to a ceiling effect). Thus for both dyslexics and non-dyslexics the overall order of difficulty on the division tables from the least to most difficult was: ÷1, ÷2, ÷10, ÷5, ÷3, ÷11, ÷4, ÷9, ÷6, ÷7, ÷8 and ÷12.

Then a study was made of any differences between the groups within the three age bands. Analysis of variance on the mean proportion correct showed an age effect ($p < 0.001$) and an age and group effect ($p < 0.01$). Post hoc tests showed that there was a significant difference ($p < 0.01$) between the young and medium age bands but not between the medium and old age bands. t-Test results comparing the groups showed that the greatest difference between the groups was in the young age band ($p < 0.001$) and secondly in the old age band ($p < 0.05$) but not in the medium age band (ns).

A comparison of age bands (groups combined) using analysis of variance gave a significant difference between the age bands on all division tables at $p < 0.001$ except for ÷1 and ÷2 ($p < 0.01$) and ÷10 ($p < 0.05$) (see Table 7.2). Post hoc tests on division tables showed no differences between the medium and old age bands on all tables (ns) and also between the young and medium age bands on ÷1, ÷2, ÷5 and ÷10 (ns). The other eight tables were significantly different between the young and medium age bands, the ÷8 being the most significantly different ($p < 0.001$).

Young dyslexics compared to young controls

Is the gap between the dyslexics and the controls constant across the age bands? The answer is 'no'. The young dyslexics perform particularly poorly in relation to the controls. They responded correctly on 52% of the questions whereas the young controls were accurate on 83% of the questions. The standard deviation was 0.23 for the young dyslexics compared to 0.09 for the young controls and thus there was greater variability among the dyslexic responses.

The young controls were least accurate on the ÷8 with 85 questions answered correctly out of 120. In contrast the young dyslexics scored below 85 correct on *all* tables except for ÷1 and ÷2. The difference between the two groups was greatest on the ÷6, ÷7, ÷8, ÷9 and ÷12. The young dyslexics were accurate on 36 out of 120 questions on the ÷8, which was their least accurate table. The difference between the least (÷8) and greatest (÷1) number correct for the young controls was 31 responses whereas this number was 66 for the young dyslexics, thus the dyslexics made a greater range of responses than the controls. A Chi-squared test was conducted showing that the young dyslexics performed significantly differently from the young controls on division ($p < 0.01$).

Medium-age dyslexics compared to medium-age controls

The medium-age dyslexics did not perform significantly differently from the medium-age controls (Chi-squared = ns). As with the young age band the tables producing the largest number of incorrect responses were the 6, 7, 8, 9 and 12 division tables. The range of correct responses from least (÷8, ÷9) to greatest (÷1) was 20 responses for the controls and 35 responses for the dyslexics.

Old dyslexics compared to old controls

A Chi-squared test showed no significant difference between the dyslexics and controls on division with the least difference being on the ÷2. The greatest difference between the two groups was on the 6, 7, 8, 9 and 12 division tables.

The answer to Question 1 is that the dyslexics do make fewer correct responses than non-dyslexics, especially and significantly in the age range 9:5 years to 11:4 years.

Question 2: *Do younger dyslexics make fewer correct responses than older dyslexics?*

While there is a general trend for both groups to show an improvement with age, comparison of Figure 7.5 with Figure 7.6 shows that the gap between the young dyslexics and the two older age bands is more marked than in the control group.

Comparing the young dyslexics to the medium-age dyslexics

How did the young dyslexics perform in comparison to the medium-age dyslexics? A Kolmogorov-Smirnov test showed that the performance by the medium-age dyslexics was significantly better than the young dyslexics ($p < 0.01$) but not so for the controls (ns). A difference of greater than 40 correct responses in favour of the medium-age dyslexics was recorded on the 3, 4, 6, 7, 8, 9 and 12 division tables. In contrast the greatest difference in favour of the medium-age controls was recorded for the ÷7 (18 more responses given by the medium-age controls than the young controls on this table).

Comparing the medium-age dyslexics to the old dyslexics

A Kolmogorov-Smirnov test comparing the medium-age dyslexics to the old dyslexics showed no difference. The same was found for the control group. On eight tables the medium-age dyslexics were more correct than the old dyslexics (particularly on the ÷8 with 13 more correct answers), whereas this was found on four tables (÷1, ÷4, ÷10, ÷11) for the controls, with particular improvement with age on the ÷8 and ÷9.

The young dyslexics compared to the old dyslexics were significantly different ($p < 0.05$) and the same was also found for the controls ($p < 0.05$).

Thus, in answer to Question 2, the young dyslexics made significantly fewer correct responses than the medium-age dyslexics and than the old dyslexics. This difference was not maintained from the medium-age to the old age band but there was a small decrease in correct responses in the oldest dyslexic age band from the peak results made by the medium-age dyslexics.

Question 3: *Are there any special number combinations, which are more likely than others to generate errors?*

Where division tables have obvious algorithms how do the dyslexics do in relation to the non-dyslexics? A similar choice of questions was prepared for the 'X_D' and 'Y_D' conditions as for multiplication, where the divisors were 10 and 11 and the quotients were 6, 7, 8 and 9 for the 'X_D' condition (a condition that included division tables with obvious algorithms). The 'Y_D' condition had 7 and 8 as divisors and the same quotients as for the 'X_D' condition.

The results for the 'X_D' condition showed that the young dyslexics were significantly less accurate than the young controls ($p < 0.001$), with 55 correct responses out of a total of 80, whereas the young controls made 79 correct responses. There was no such difference found between the groups in the medium and old age bands.

How did dyslexics perform compared to controls on the 'Y_D' condition – which included questions that were now known to be more of a challenge to both groups because they received lower accuracy scores (see section 7.5 on order of difficulty)? Both the young and old dyslexics made significantly less correct responses than their age matched controls ($p < 0.001$) and the medium-age dyslexics were also significantly weaker than the medium-age controls ($p < 0.05$) on the 'Y_D' condition.

Thus throughout the age bands the dyslexics found the division tables with no obvious algorithm harder to answer accurately than the non-dyslexics. It is interesting to note that the old dyslexics were as significantly as far behind the old controls as the young dyslexics were behind the young controls on this harder condition.

The young age band recorded a significant difference ($p < 0.01$) between the 'X_D' and 'Y_D' condition and this was further investigated by the use of a Chi-squared test showing that the differential between the 'X_D' and 'Y_D' conditions was significantly different for the dyslexics than for the controls in the young age band ($p < 0.01$).

Therefore, in answer to Question 3: there are special number combinations where the dyslexics perform particularly and significantly more poorly than controls – these combinations involve division tables for which there are no obvious algorithms on which the dyslexics can rely.

<u>CHAPTER 8</u>

Correctness on Addition Tasks

8.1 Aims of This chapter
8.2 Overall Comparisons
8.3 Tasks Within Addition
8.4 Comparing Age Bands Within the Separate Groups
8.5 Order of Difficulty
8.6 Special Number Combinations
8.7 Chapter Summary – Questions Answered

8.1 Aims of This Chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of addition:

(1) Do dyslexics make fewer correct responses than non-dyslexics?

(2) Do younger dyslexics make fewer correct responses than older dyslexics?

(3) Are there any special number combinations that are more likely than others to generate errors?

8.2 Overall Comparisons

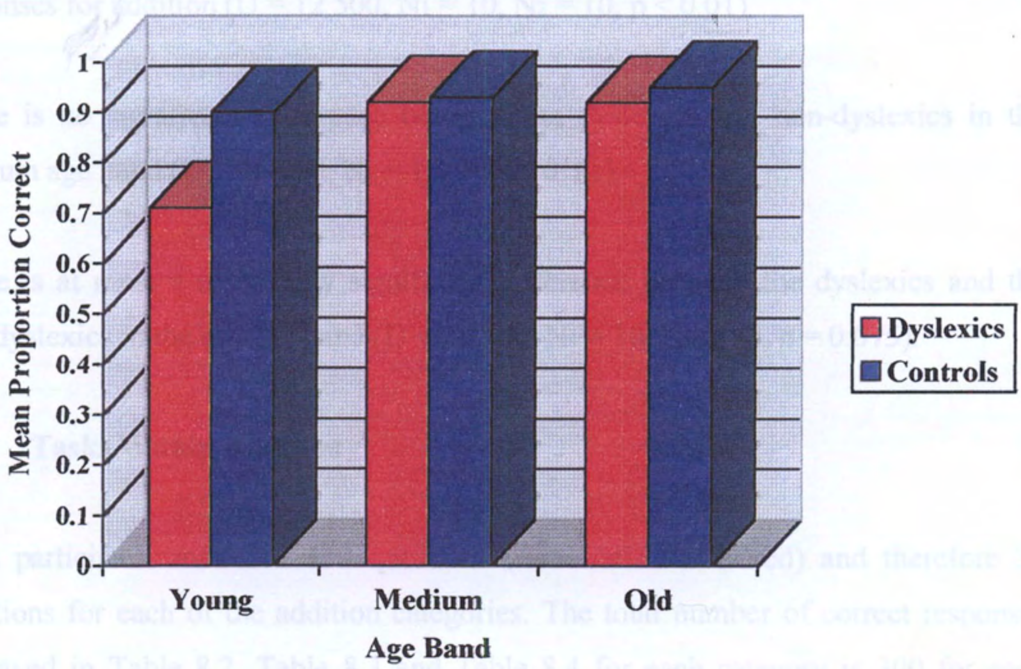
A total of 9,000 addition questions were given to 30 dyslexics and 30 controls who were divided into three age bands. There were 10 participants in each group/age band, who were each given 150 addition questions (Trial 1 and Trial 2 data presented together), therefore the sum of responses was 1,500 for each group/age band.

The mean proportion of correct responses for each group and age band is reported in Table 8.1 and Figure 8.1.

Table 8.1 Mean proportion of correct responses for each group and age band on addition

Age	*Group*	*Mean proportion correct*	*Standard deviation*
Young	Dyslexics	0.71	0.17
	Controls	0.90	0.07
Medium	Dyslexics	0.92	0.04
	Controls	0.93	0.06
Old	Dyslexics	0.92	0.04
	Controls	0.95	0.03

Figure 8.1 Mean proportion of correct responses for each group and age band on addition



Analysis of variance showed the following overall results:

- An age effect ($F(2, 54) = 14.485, p < 0.001$)
- A group effect ($F(1, 54) = 12.078, p < 0.001$)
- An age and group effect ($F(2, 54) = 7.663, p < 0.001$)

Analysis of variance tables are presented in Appendix F3.

Post hoc tests (Tamhane) showed:

- Young compared to medium age band: $p < 0.05$
- Medium compared to old age band: ns
- Young compared to old age band: $p < 0.01$

Non-parametric tests (Mann-Whitney) showed that there is a significant difference between dyslexics and non-dyslexics in the young age band on the number of correct responses for addition ($U = 12.500, N_1 = 10, N_2 = 10, p < 0.01$).

There is no significant difference between the dyslexics and non-dyslexics in the medium age band ($U = 46.000, N_1 = 10, N_2 = 10$, ns).

There is at most a marginally significant difference between the dyslexics and the non-dyslexics in the old age band ($U = 26.500, N_1 = 10, N_2 = 10, p = 0.075$).

8.3 Tasks Within Addition

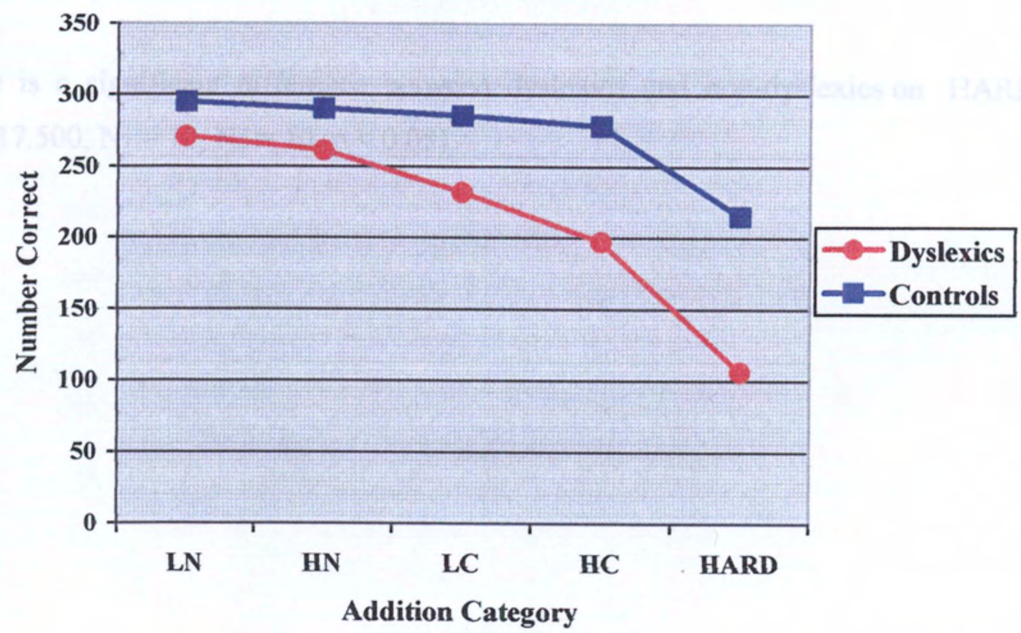
Each participant answered 150 questions (two trials conducted) and therefore 30 questions for each of the addition categories. The total number of correct responses displayed in Table 8.2, Table 8.3 and Table 8.4 for each category is 300 for each group/age band. The results are illustrated in Figures 9.2, 9.3 and 9.4.

8.3.1 Young Age Band and the Five Categories

Table 8.2 Number of correct responses made by the dyslexics and non-dyslexics in the young age band, broken down by category

Addition category	*Young age band*	
	Dyslexics	*Controls*
LN	271	295
HN	261	290
LC	232	285
HC	197	278
HARD	106	215

Figure 8.2 Number of correct responses by the two groups in the young age band



Chi-squared = 23.089, df = 4, $p < 0.001$.

The performance of the dyslexics is different on the number of correct answers on addition compared to the controls. The young dyslexics significantly underperform the controls across all the categories.

Non-parametric Mann-Whitney tests showed:

There is a significant difference between dyslexics and non-dyslexics on LN ($U = 23.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$).

There is a significant difference between dyslexics and non-dyslexics on HN ($U = 8.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.001$).

There is a significant difference between dyslexics and non-dyslexics on LC ($U = 17.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$).

There is a significant difference between dyslexics and non-dyslexics on HC ($U = 14.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.01$).

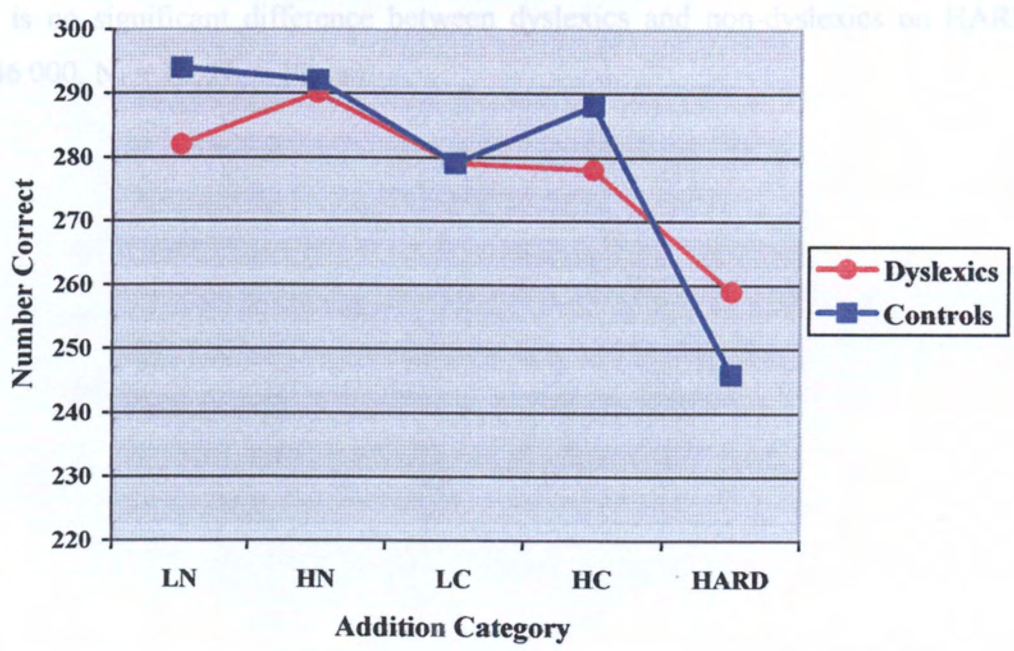
There is a significant difference between dyslexics and non-dyslexics on HARD ($U = 17.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$).

8.3.2 Medium Age Band and the Five Categories

Table 8.3. Number of correct responses made by the dyslexics and non-dyslexics in the medium age band, broken down by category

Addition category	*Medium age band*	
	Dyslexics	*Controls*
LN	282	294
HN	290	292
LC	279	279
HC	278	288
HARD	259	246

Figure 8.3 Number of correct responses by the two groups in the medium age band



Chi-squared = 0.7248, df = 4, ns.

The performance of the dyslexics and controls is significantly similar across all categories.

Non-parametric Mann-Whitney tests showed:

There is no significant difference between dyslexics and non-dyslexics on LN ($U = 33.000$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on HN ($U = 34.500$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on LC ($U = 49.000$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on HC ($U = 40.000$, $N_1 = 10$, $N_2 = 10$, ns).

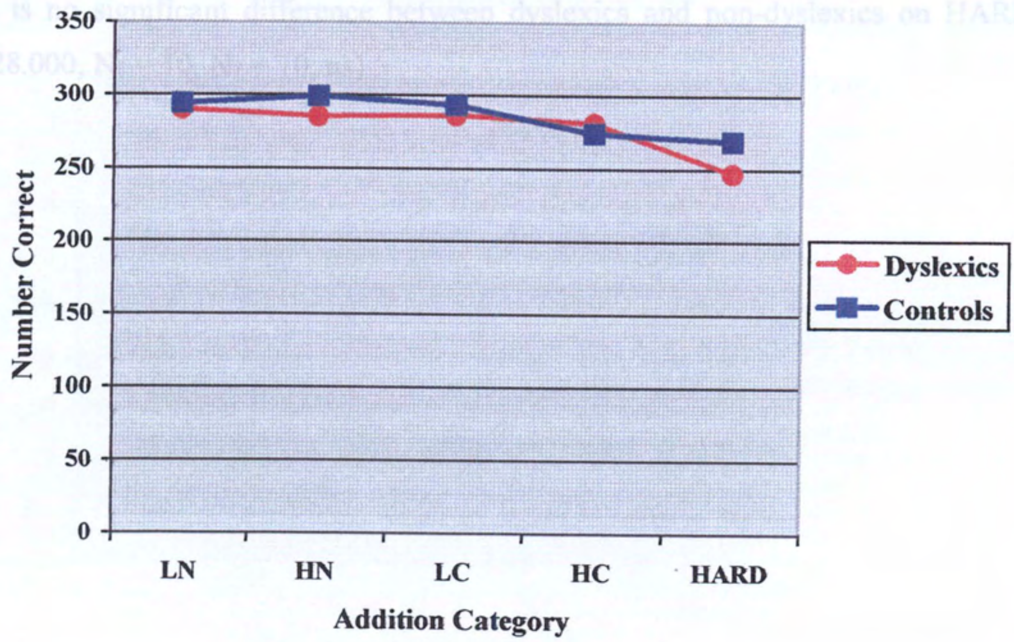
There is no significant difference between dyslexics and non-dyslexics on HARD ($U = 46.000$, $N_1 = 10$, $N_2 = 10$, ns).

8.3.3 Old Age Band and the Five Categories

Table 8.4 Number of correct responses made by the dyslexics and non-dyslexics in the old age band, broken down by category

Addition category	*Old age band*	
	Dyslexics	*Controls*
LN	290	294
HN	285	299
LC	286	293
HC	281	274
HARD	247	269

Figure 8.4 Number of correct responses by the two groups in the old age band



Chi-squared = 0.9063, df = 4, ns.

The performance of the dyslexics and controls is significantly similar across all categories.

Non-parametric Mann-Whitney tests showed:

There is no significant difference between dyslexics and non-dyslexics on LN ($U = 44.000$, $N_1 = 10$, $N_2 = 10$, ns).

There is a significant difference between dyslexics and non-dyslexics on HN ($U = 14.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.01$).

There is a significant difference between dyslexics and non-dyslexics on LC ($U = 22.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$).

There is no significant difference between dyslexics and non-dyslexics on HC ($U = 37.500$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on HARD ($U = 28.000$, $N_1 = 10$, $N_2 = 10$, ns).

8.4 Comparing Age Bands Within the Separate Groups

This is illustrated in Figures 8.5 and 8.6.

Figure 8.5 Number of correct responses made by the 3 age bands in the dyslexic group on addition tasks

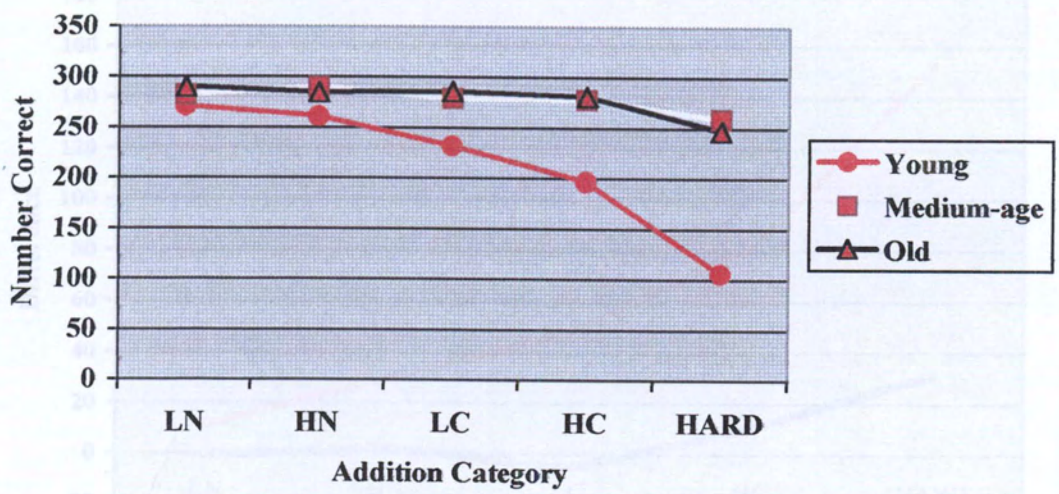
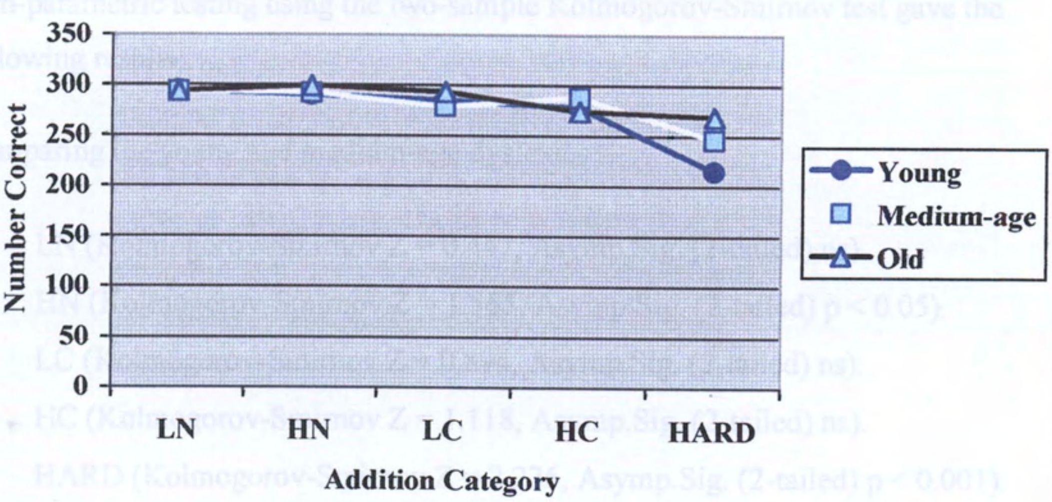


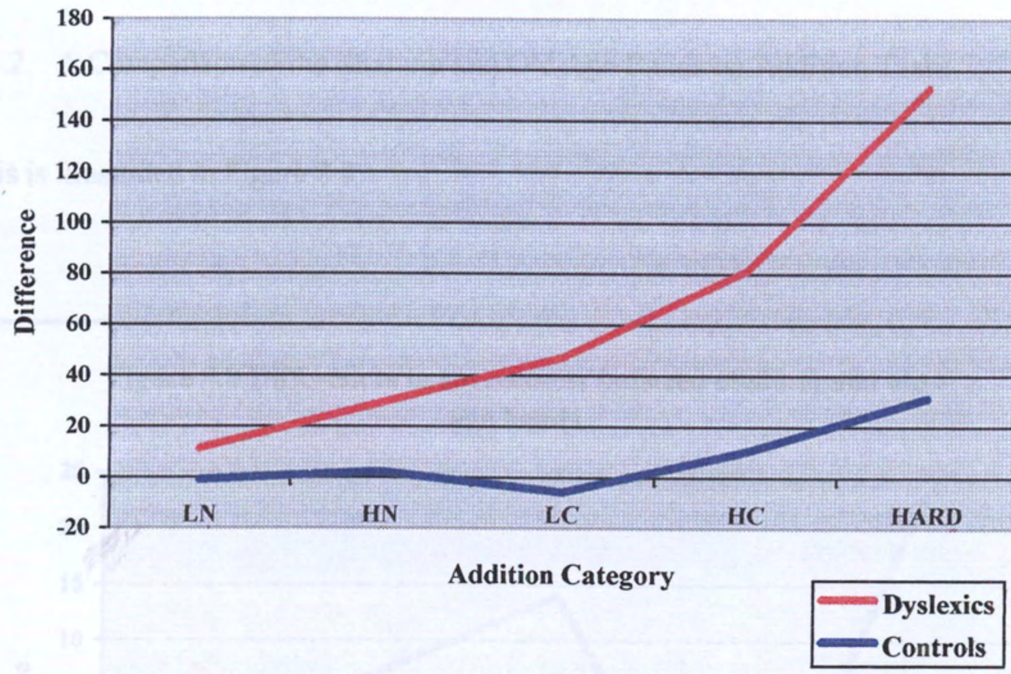
Figure 8.6 Number of correct responses made by the 3 age bands in the control group on addition tasks



8.4.1 A Comparison of the Young and Medium Age Bands on Addition Tasks

This is illustrated in Figure 8.7.

Figure 8.7 Differences in correctness between young and medium age bands



Non-parametric testing using the two-sample Kolmogorov-Smirnov test gave the following results:

Comparing the young and medium-age dyslexics:

- LN (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$).
- LC (Kolmogorov-Smirnov Z = 0.894, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 1.118, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 2.236, Asymp.Sig. (2-tailed) $p < 0.001$).

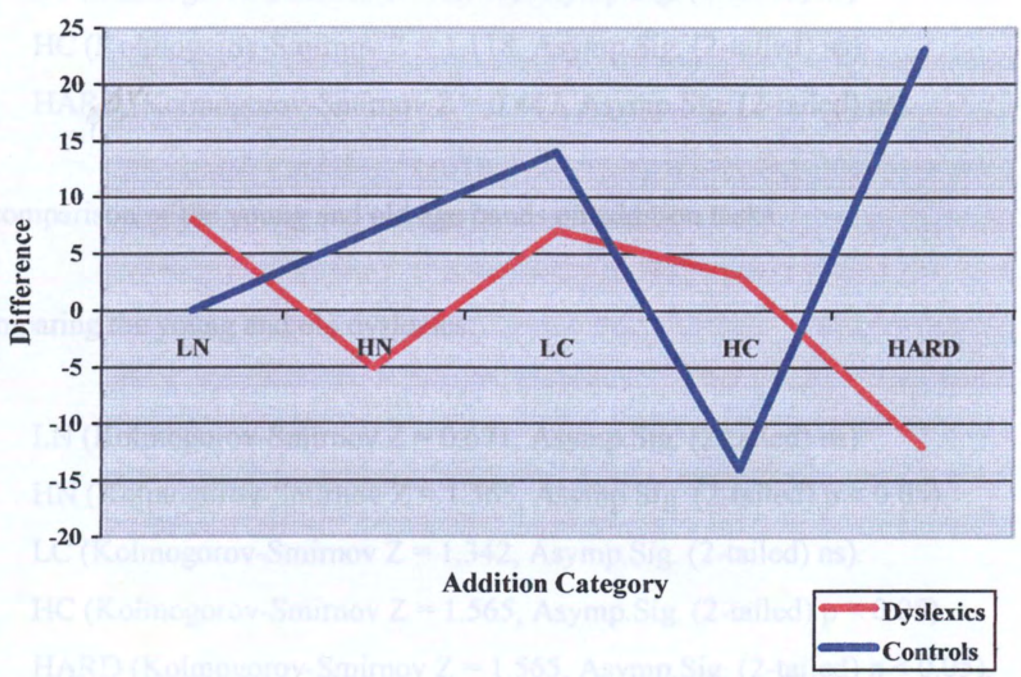
Comparing the young and medium-age controls:

- LN (Kolmogorov-Smirnov Z = 0.224, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 1.118, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 0.894, Asymp.Sig. (2-tailed) ns).

8.4.2 A Comparison of the Medium and Old Age Bands on Addition Tasks

This is illustrated in Figure 8.8.

Figure 8.8 Differences in correctness between medium and old age bands



Non-parametric testing using the two-sample Kolmogorov-Smirnov test gave the following results:

Comparing the medium-age and old dyslexics:

- LN (Kolmogorov-Smirnov Z = 0.224, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 0.894, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).

Comparing the medium-age and old controls:

- LN (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 1.342, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 1.118, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).

A comparison of the young and old age bands on addition tasks:

Comparing the young and old dyslexics:

- LN (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$).
- LC (Kolmogorov-Smirnov Z = 1.342, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$).
- HARD (Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$).

Comparing the young and old controls:

- LN (Kolmogorov-Smirnov Z = 0.224, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 1.342, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 0.894, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 1.118, Asymp.Sig. (2-tailed) ns).

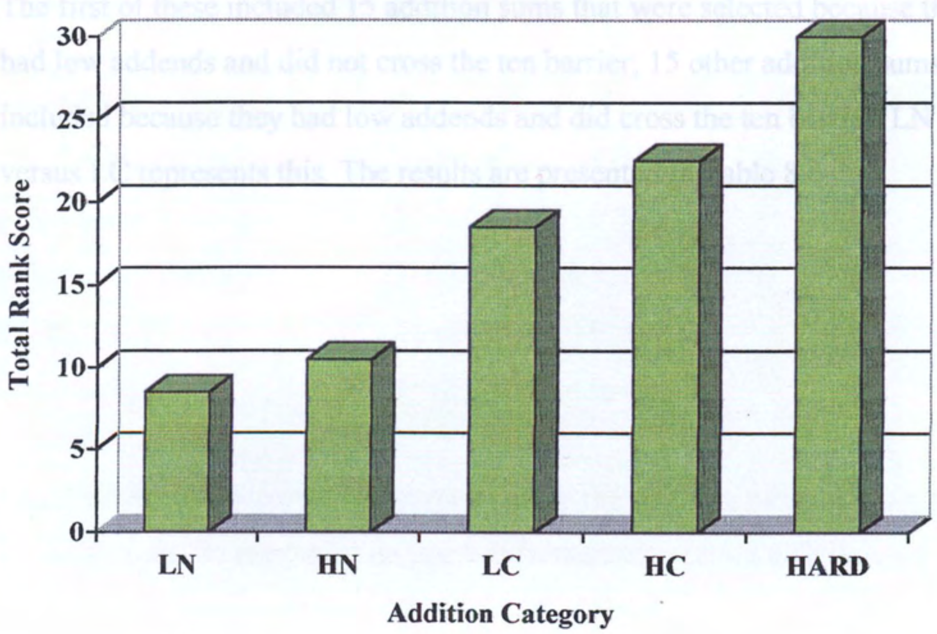
8.5 Order of Difficulty

This chapter is concerned with the number of correct responses given by dyslexics and non-dyslexics in response to addition tasks. Table 8.5 shows the rank order of correct responses given on each addition category by dyslexics and non-dyslexics in each age band. The ranking begins with the addition category answered most correctly. The ranks have been totalled to give a total rank score and an overall rank has been found from this. The results are illustrated in Figure 8.9.

Table 8.5 Rank order on correct responses for each addition category by group and age band

Addition category	*Dyslexics*			*Controls*			*Total*	*Standard order*
	Age Band							
	Young	*Medium-age*	*Old*	*Young*	*Medium-age*	*Old*		
LN	1	2	1	1	1	2.5	8.5	1
HN	2	1	2.5	2	2	1	10.5	2
LC	3	3.5	2.5	3	4	2.5	18.5	3
HC	4	3.5	4	4	3	4	22.5	4
HARD	5	5	5	5	5	5	30	5

Figure 8.9 Addition category total rank scores for all groups and age bands combined



A correlation analysis indicates that there is an overall strong and positive correlation between the orders of difficulty irrespective of group and age band.

Spearman rho = 0.9178, $p < 0.001$.

The order of difficulty on addition categories is: LN, HN, LC, HC and HARD.

8.6 Special Number Combinations

Are there any special number combinations for addition that are more likely than others to generate errors?

How big an effect do low or high addends, crossing or not crossing the ten barrier, have on dyslexics and is this effect similar for non-dyslexics? What are the factors in addition which affect accuracy?

Several groupings of addition sums were chosen to test these questions.

(1) The first of these included 15 addition sums that were selected because they had low addends and did not cross the ten barrier; 15 other addition sums were included because they had low addends and did cross the ten barrier. LN versus LC represents this. The results are presented in Table 8.6.

Table 8.6 Number of correct responses by groups and age bands in the LN and LC type condition for addition

Groups and age bands	*LN condition*	*LC condition*
Young age band		
Dyslexics	271	232
Controls	295	285
Medium age band		
Dyslexics	282	279
Controls	294	279
Old age band		
Dyslexics	290	286
Controls	294	293

t-Test results on paired samples LN and LC for groups and age bands are as follows:

- Young dyslexics ($t = 1.789$, $df = 9$, ns)
- Young controls ($t = 0.000$, $df = 9$, ns)
- Medium-age dyslexics ($t = 0.449$, $df = 9$, ns)
- Medium-age controls ($t = 0.958$, $df = 9$, ns)
- Old dyslexics ($t = 1.616$, $df = 9$, ns)
- Old controls ($t = 2.077$, $df = 9$, ns)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band (for which conditions are combined on this test throughout section 8.6) showed:

- Young ($U = 17.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$)
- Medium-age ($U = 40.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 28.000$, $N_1 = 10$, $N_2 = 10$, ns)

(2) The second of these included 15 addition sums that were selected because they had high addends and did not cross the ten barrier; 15 other addition sums were included because they had high addends and did cross the ten barrier. HN versus HC represents this. The results are presented in Table 8.7.

Table 8.7 Number of correct responses by groups and age bands in the HN and HC type condition for addition

Groups and age bands	*HN condition*	*HC condition*
Young age band		
Dyslexics	261	197
Controls	290	278
Medium age band		
Dyslexics	290	278
Controls	292	288
Old age band		
Dyslexics	285	281
Controls	299	274

t-Test results on paired samples HN and HC for groups and age bands are as follows:

- Young dyslexics ($t = 2.533$, $df = 9$, $p < 0.05$)
- Young controls ($t = 1.908$, $df = 9$, ns)
- Medium-age dyslexics ($t = 1.365$, $df = 9$, ns)
- Medium-age controls ($t = 0.688$, $df = 9$, ns)
- Old dyslexics ($t = 0.667$, $df = 9$, ns)
- Old controls ($t = 6.228$, $df = 9$, $p < 0.001$)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band showed:

- Young ($U = 4.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.001$)
- Medium-age ($U = 34.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 41.500$, $N_1 = 10$, $N_2 = 10$, ns)

(3) The third of these included 15 addition sums that were selected because they had low addends and did not cross the ten barrier; 15 other addition sums were included because they had high addends but did not cross the ten barrier. LN versus HN represents this. The results are presented in Table 8.8.

Table 8.8 Number of correct responses by groups and age bands in the LN and HN type condition for addition

Groups and age bands	*LN condition*	*HN condition*
Young age band		
Dyslexics	271	261
Controls	295	290
Medium age band		
Dyslexics	282	290
Controls	294	292
Old age band		
Dyslexics	290	285
Controls	294	299

t-Test results on paired samples LN and HN for groups and age bands are as follows:

- Young dyslexics (t = 0.569, df = 9, ns)
- Young controls (t = 1.342, df = 9, ns)
- Medium-age dyslexics (t = 2.409, df = 9, $p < 0.05$)
- Medium-age controls (t = 2.449, df = 9, $p < 0.05$)
- Old dyslexics (t = 0.808, df = 9, ns)
- Old controls (t = 6.708, df = 9, $p < 0.001$)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band showed:

- Young (U = 4.000, $N_1 = 10$, $N_2 = 10$, $p < 0.001$)
- Medium-age (U = 27.500, $N_1 = 10$, $N_2 = 10$, ns)
- Old (U = 26.500, $N_1 = 10$, $N_2 = 10$, ns)

(4) The fourth of these included 15 addition sums that were selected because they had low addends and did cross the ten barrier; 15 other addition sums were included because they had high addends and did cross the ten barrier. LC versus HC represents this. The results are presented in Table 8.9.

Table 8.9 Number of correct responses by groups and age bands in the LC and HC type condition for addition

Groups and age bands	*LC condition*	*HC condition*
Young age band		
Dyslexics	232	197
Controls	285	278
Medium age band		
Dyslexics	279	278
Controls	279	288
Old age band		
Dyslexics	286	281
Controls	293	274

t-Test results on paired samples LC and HC for groups and age bands are as follows:

- Young dyslexics ($t = 2.907$, $df = 9$, $p < 0.05$)
- Young controls ($t = 1.137$, $df = 9$, ns)
- Medium-age dyslexics ($t = 0.161$, $df = 9$, ns)
- Medium-age controls ($t = 1.711$, $df = 9$, ns)
- Old dyslexics ($t = 1.246$, $df = 9$, ns)
- Old controls ($t = 8.143$, $df = 9$, $p < 0.001$)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band showed:

- Young ($U = 14.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.01$)
- Medium-age ($U = 43.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 40.500$, $N_1 = 10$, $N_2 = 10$, ns)

(5) The fifth of these included 15 addition sums that were selected because they had high addends and did not cross the ten barrier; 15 other addition sums were included because they had low addends and did cross the ten barrier. HN versus LC represents this. The results are presented in Table 8.10.

Table 8.10 Number of correct responses by groups and age bands in the HN and LC type condition for addition

Groups and age bands	*HN condition*	*LC condition*
Young age band		
Dyslexics	261	232
Controls	290	285
Medium age band		
Dyslexics	290	279
Controls	292	279
Old age band		
Dyslexics	285	286
Controls	299	293

t-Test results on paired samples HN and LC for groups and age bands are as follows:

- Young dyslexics (t = 1.560, df = 9, ns)
- Young controls (t = 0.958, df = 9, ns)
- Medium-age dyslexics (t = 1.718, df = 9, ns)
- Medium-age controls (t = 2.112, df = 9, ns)
- Old dyslexics (t = 0.156, df = 9, ns)
- Old controls (t = 1.964, df = 9, ns)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band showed:

- Young (U = 37.000, $N_1 = 10$, $N_2 = 10$, ns)
- Medium-age (U = 34.500, $N_1 = 10$, $N_2 = 10$, ns)
- Old (U = 12.500, $N_1 = 10$, $N_2 = 10$, $p < 0.01$)

(6) The sixth of these included 15 addition sums that were selected because they had low addends and did not cross the ten barrier and 15 other addition sums were included because they had high addends, a two digit number added to a two digit number and did cross the ten barrier. LN versus HARD represents this. The results are presented in Table 8.11.

Table 8.11 Number of correct responses by groups and age bands in the LN and HARD type condition for addition

Groups and age bands	*LN condition*	*HARD condition*
Young age band		
Dyslexics	271	106
Controls	295	215
Medium age band		
Dyslexics	282	259
Controls	294	246
Old age band		
Dyslexics	290	247
Controls	294	269

t-Test results on paired samples LN and HARD for groups and age bands are as follows:

- Young dyslexics (t = 5.968, df = 9, $p < 0.001$)
- Young controls (t = 3.329, df = 9, $p < 0.01$)
- Medium-age dyslexics (t = 2.847, df = 9, $p < 0.05$)
- Medium-age controls (t = 2.076, df = 9, ns)
- Old dyslexics (t = 3.851, df = 9, $p < 0.01$)
- Old controls (t = 1.671, df = 9, ns)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band showed:

- Young (U = 21.000, $N_1 = 10$, $N_2 = 10$, $p < 0.05$)
- Medium-age (U = 47.500, $N_1 = 10$, $N_2 = 10$, ns)
- Old (U = 30.000, $N_1 = 10$, $N_2 = 10$, ns)

(7) The seventh of these included 30 addition sums that were selected because they had low/high addends and did not cross the ten barrier; 30 other addition sums were included because they had low/high addends and did cross the ten barrier. This is represented by LN/HN versus LC/HC. The results are presented in Table 8.12.

Table 8.12 Number of correct responses by groups and age bands in the LN/HN and LC/HC type condition for addition

Groups and age bands	*LN/HN condition*	*LC/HC condition*
Young age band		
Dyslexics	532	429
Controls	585	563
Medium age band		
Dyslexics	572	557
Controls	586	567
Old age band		
Dyslexics	575	567
Controls	593	567

t-Test results on paired samples LN/HN and LC/HC for groups and age bands are as follows:

- Young dyslexics ($t = 2.324$, $df = 9$, $p < 0.05$)
- Young controls ($t = 1.585$, $df = 9$, ns)
- Medium-age dyslexics ($t = 0.797$, $df = 9$, ns)
- Medium-age controls ($t = 1.029$, $df = 9$, ns)
- Old dyslexics ($t = 0.259$, $df = 9$, ns)
- Old controls ($t = 2.058$, $df = 9$, ns)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band showed:

- Young ($U = 31.500$, $N_1 = 10$, $N_2 = 10$, ns)
- Medium-age ($U = 46.500$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 32.000$, $N_1 = 10$, $N_2 = 10$, ns)

(8) The eighth of these included 30 addition sums that were selected because they had low addends; 30 other addition sums were included because they had high addends. This is represented by LN/LC versus HN/HC. The results are presented in Table 8.13.

Table 8.13 Number of correct responses by groups and age bands in the LN/LC and HN/HC type condition for addition

Groups and age bands	*LN/LC condition*	*HN/HC condition*
Young age band		
Dyslexics	503	458
Controls	580	568
Medium age band		
Dyslexics	561	568
Controls	573	580
Old age band		
Dyslexics	576	566
Controls	587	573

t-Test results on paired samples LN/LC and HN/HC for groups and age bands are as follows:

- Young dyslexics ($t = 2.954$, $df = 9$, $p < 0.05$)
- Young controls ($t = 0.309$, $df = 9$, ns)
- Medium-age dyslexics ($t = 2.414$, $df = 9$, $p < 0.05$)
- Medium-age controls ($t = 3.042$, $df = 9$, $p < 0.05$)
- Old dyslexics ($t = 0.000$, $df = 9$, ns)
- Old controls ($t = 1.177$, $df = 9$, ns)

Non-parametric Mann-Whitney 'U' tests comparing the two groups in each age band showed:

- Young (U = 22.000, N_1 = 10, N_2 = 10, $p < 0.05$)
- Medium-age (U = 42.500, N_1 = 10, N_2 = 10, ns)
- Old (U = 42.000, N_1 = 10, N_2 = 10, ns)

8.7 Chapter Summary – Questions Answered

Question 1: *Do dyslexics make fewer correct responses than non-dyslexics?*

The answer to this question is 'yes'. An analysis of variance on mean proportion of correct responses made by the two groups and three age bands gave an age effect, a group effect and a group/age effect all at $p < 0.001$. Post hoc tests showed a significant difference between the young and medium age bands (groups combined) ($p < 0.05$) and between the young and old age band ($p < 0.01$) but no significant difference between the medium and old age band. Non-parametric tests using Mann-Whitney showed a significant difference between the dyslexics and non-dyslexics in the young age band only ($p < 0.01$). Thus young dyslexics made fewer correct responses than non-dyslexics.

Spearman's rho correlation on the order of difficulty of the five addition categories showed that the order for the groups and age bands were significantly associated ($p < 0.001$) with the standard order, from most to least correct being: LN, HN, LC, HC and HARD. This indicates that crossing or not crossing the ten barrier is a major factor for accuracy of response.

Comparing young dyslexics with young controls

A Chi-squared test showed that the dyslexics significantly underperformed the controls across all addition categories ($p < 0.001$). Analysis of data was undertaken on young group performance on each of the categories using Mann-Whitney with LN, LC and HARD categories being significantly less correctly answered by the young dyslexics ($p < 0.05$), the significant difference on HC was $p < 0.01$ and on HN was $p < 0.001$ – both in favour of the young controls. The dyslexics on 261 questions out of 300 answered the HN category correctly and this figure was 290 correct responses for the controls. Thus on each addition category the young dyslexics were significantly less accurate than the young controls.

Comparing medium-age dyslexics with medium-age controls

There was no significant difference between the two groups overall or for any of the categories. Thus the medium-age dyslexics were performing at the same level of accuracy as the medium-age controls.

Comparing old dyslexics with old controls

A Chi-squared test showed that the performance of the dyslexics and the controls was significantly similar across all categories. A study of each category using Mann-Whitney showed that two categories HN and LC showed up a significant difference ($p < 0.01$ and $p < 0.05$ respectively) between the two groups, with the dyslexics answering fewer questions correctly.

Thus the main effect occurred in the young age band with the young dyslexics being particularly and significantly weaker at responding accurately. In the old age band significant differences on two categories were found with the dyslexics being the weaker while the medium-age dyslexics performed at the same level as their matched non-dyslexic controls.

For all groups and age bands the HARD category had the least number of correct responses.

Question 2: *Do younger dyslexics make fewer correct responses than older dyslexics?*

Figures 8.5 and 8.6 show the responses made by the three age bands for each group. The dyslexic results show that the gap is widest between the young dyslexics and the older age bands, while the gap is not evident for the controls. The HARD category was the most challenging for all.

Young dyslexics compared to medium-age dyslexics

Non-parametric tests using the two-sample Kolmogorov-Smirnov test were conducted on each category. On two categories (HN and HARD) the medium-age dyslexics performed significantly better than the young dyslexics ($p < 0.05$ and $p < 0.001$ respectively), whereas there were no categories on which the young controls differed from the medium-age controls.

Medium-age dyslexics compared to old dyslexics

No significant differences were found on any of the categories for both the dyslexics and the controls. The medium-age dyslexics were more accurate on the HN and HARD categories than the old dyslexics whereas the medium-age controls were more accurate on the HC category than the old controls.

A comparison of young dyslexics and old dyslexics using the Kolmogorov-Smirnov test showed that the old dyslexics were significantly more accurate on HN, HC and HARD ($p < 0.05$), whereas there were no significant differences on the same age comparison for the controls. Thus on categories with high addends the young dyslexics performed significantly less accurately than the old dyslexics.

Question 3: *Are there any special number combinations that are more likely than others to generate errors?*

In order to answer this question, different addition categories, independently or in combination, were compared with each other. Only results where a significant difference was found are reported here. The findings on eight comparisons are as follows:

(1) *LN compared to LC.* No significant differences were found between these two conditions for any group age band. The young controls were significantly more accurate than the young dyslexics on these two conditions combined ($p < 0.05$).

(2) *HN compared to HC.* The young dyslexics and the old controls were significantly more accurate on the HN category ($p < 0.05$ and $p < 0.001$ respectively). The young controls were significantly more accurate than the young dyslexics on these two conditions combined ($p < 0.001$).

(3) *LN compared to HN.* The medium-age controls performed significantly better on the LN category ($p < 0.05$) whereas the medium-age dyslexics and the old controls were significantly better on the HN category ($p < 0.05$ and $p < 0.001$). The young controls were significantly more accurate than the young dyslexics on these two conditions combined ($p < 0.001$).

(4) *LC compared HC.* Both the young dyslexics and the old controls were significantly less accurate on the HC category ($p < 0.05$ and $p < 0.001$ respectively). The young controls were significantly more accurate than the young dyslexics on these two conditions combined ($p < 0.01$).

(5) *HN compared to LC.* No significant differences were found between these two categories for any group age band. The old controls performed significantly better than the old dyslexics, taking both conditions combined ($p < 0.01$).

(6) *LN compared to HARD.* The young, medium-age and old dyslexics performed significantly better on the LN category ($p < 0.001$, $p < 0.05$ and $p < 0.01$ respectively) and the young controls likewise ($p < 0.01$). The young controls were significantly more accurate than the young dyslexics on these two conditions combined ($p < 0.05$).

(7) *Not crossing (LN and HN combined) compared to crossing (LC and HC combined) the ten barrier.* The young dyslexics performed significantly better on the not crossing combination ($p < 0.05$).

(8) *Low addends (LN and LC combined) compared to high addends (HN and HC combined).* The young dyslexics performed significantly better on the Low addends combination ($p < 0.05$) whereas the medium-age dyslexics and the medium-age controls were significantly less accurate on the Low addends combination ($p < 0.05$). The young controls were significantly more accurate than the young dyslexics on these combinations combined ($p < 0.05$).

Thus on six out of the eight investigations the young dyslexics were significantly less accurate than the young controls when the conditions were combined. Additionally the young dyslexics were significantly affected by the size of the addends and the ten barrier. They performed significantly better when the addends were low as compared to high (condition 4, 6 and 8) and when the addition sums didn't involve crossing the ten barrier (condition 2 and 7).

The medium-age dyslexics were significantly more accurate where the comparison involved low and high addends – performing more accurately on the questions with high addends (excluding HARD).

The only significant difference in correct responses made by the old dyslexics was on LN compared to HARD, otherwise their responses on all other comparisons were not found to be statistically different.

CHAPTER 9

Correctness on Subtraction Tasks

9.1 Aims of This Chapter
9.2 Overall Comparisons
9.3 Tasks Within Subtraction
9.4 Comparing Age Bands Within the Separate Groups
9.5 Order of Difficulty
9.6 Special Number Combinations
9.7 Chapter Summary – Questions Answered

9.1 Aims of This Chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of subtraction:

(1) Do dyslexics make fewer correct responses than non-dyslexics?

(2) Do younger dyslexics make fewer correct responses than older dyslexics?

(3) Are there any special number combinations that are more likely than others to generate errors?

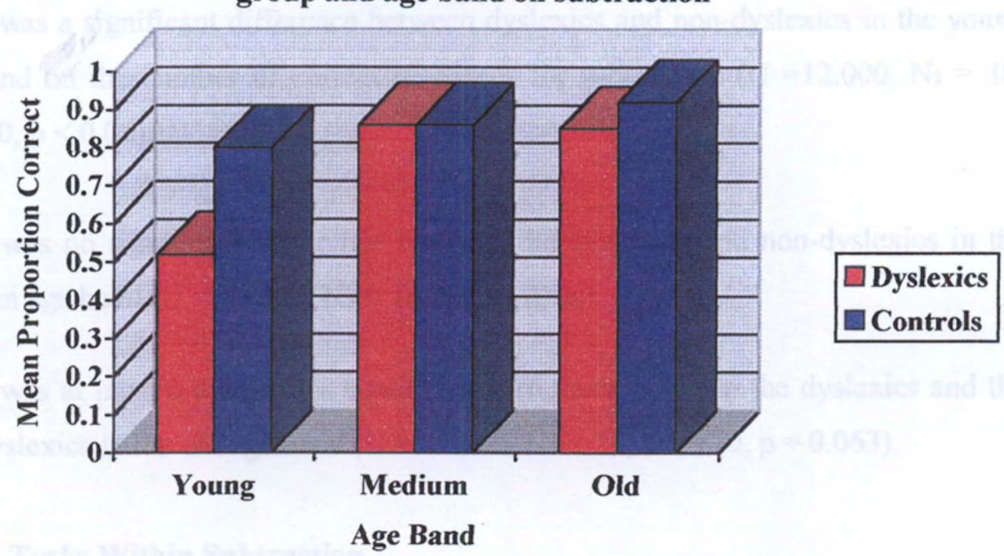
9.2 Overall Comparisons

A total of 9,000 subtraction questions were given to 30 dyslexics and 30 controls who were divided into three age bands. There were 10 participants in each group/age band, who were each given 150 subtraction questions (Trial 1 and Trial 2 data presented together), therefore the sum of the correct/incorrect responses is 1,500 for each group/age band. Table 9.1 and Figure 9.1 show the results of the mean proportion of correct responses for each group and age band.

Table 9.1 Mean proportion of correct responses for each group and age band on subtraction

Age	*Group*	*Mean proportion correct*	*Standard deviation*
Young	Dyslexics	0.52	0.18
	Controls	0.80	0.10
Medium	Dyslexics	0.86	0.10
	Controls	0.86	0.10
Old	Dyslexics	0.85	0.10
	Controls	0.92	0.05

Figure 9.1 Mean proportion of correct responses for each group and age band on subtraction



Analysis of variance showed the following overall results:

- An age effect ($F(2, 54) = 25.691$, $p < 0.001$)
- A group effect ($F(1, 54) = 16.581$, $p < 0.001$)
- An age and group effect ($F(2, 54) = 8.546$, $p < 0.001$)

Analysis of variance tables are presented in Appendix F4.

Post hoc tests (Tamhane) showed:

- Young compared to medium age band: $p < 0.001$
- Medium compared to old age band: ns
- Young compared to old age band: $p < 0.001$

A non-parametric Mann-Whitney 'U' test showed:

There was a significant difference between dyslexics and non-dyslexics in the young age band on the number of correct responses for subtraction ($U = 12.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.01$).

There was no significant difference between the dyslexics and non-dyslexics in the medium age band ($U = 47.500$, $N_1 = 10$, $N_2 = 10$, ns).

There was at most a marginally significant difference between the dyslexics and the non-dyslexics in the old age band ($U = 25.000$, $N_1 = 10$, $N_2 = 10$, $p = 0.063$).

9.3 Tasks Within Subtraction

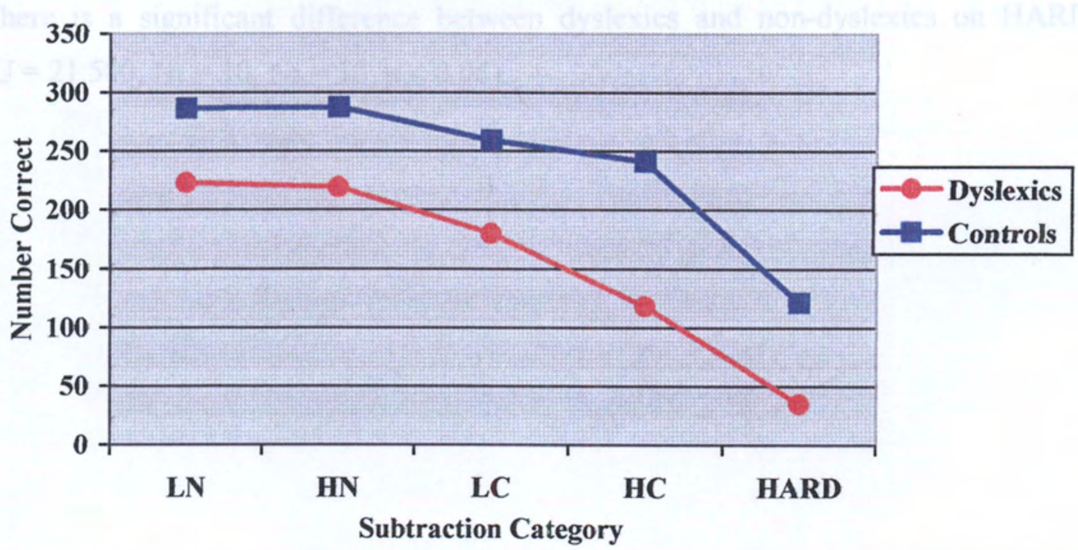
Each participant answered 150 subtraction questions (both trials together) and therefore 30 questions for each of the five subtraction categories. The total number of correct responses, displayed in Table 9.2, Table 9.3 and Table 9.4, for each subtraction category, per group/age band recorded, is 300 responses (30 questions × 10 participants). The results are illustrated in Figures 9.2, 9.3 and 9.4.

9.3.1 Young Age Band and the Five Subtraction Categories

Table 9.2 Number of correct responses made by the dyslexics and non-dyslexics in the young age band, broken down by category

	Young age band	
Subtraction category	*Dyslexics*	*Controls*
LN	223	286
HN	219	287
LC	180	259
HC	118	241
HARD	35	121

Figure 9.2 Number of correct responses made by the two groups on subtraction categories - young age band



Chi-squared = 33.038, df = 4, $p < 0.001$.

The performance of the dyslexics is different on the number of correct answers on subtraction compared to the controls. The young dyslexics significantly underperform the controls across all the categories.

A non-parametric Mann-Whitney 'U' test showed:

There is a significant difference between dyslexics and non-dyslexics on LN ($U = 4.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.001$).

There is a significant difference between dyslexics and non-dyslexics on HN ($U = 13.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.01$).

There is a significant difference between dyslexics and non-dyslexics on LC ($U = 19.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$).

There is a significant difference between dyslexics and non-dyslexics on HC ($U = 9.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.001$).

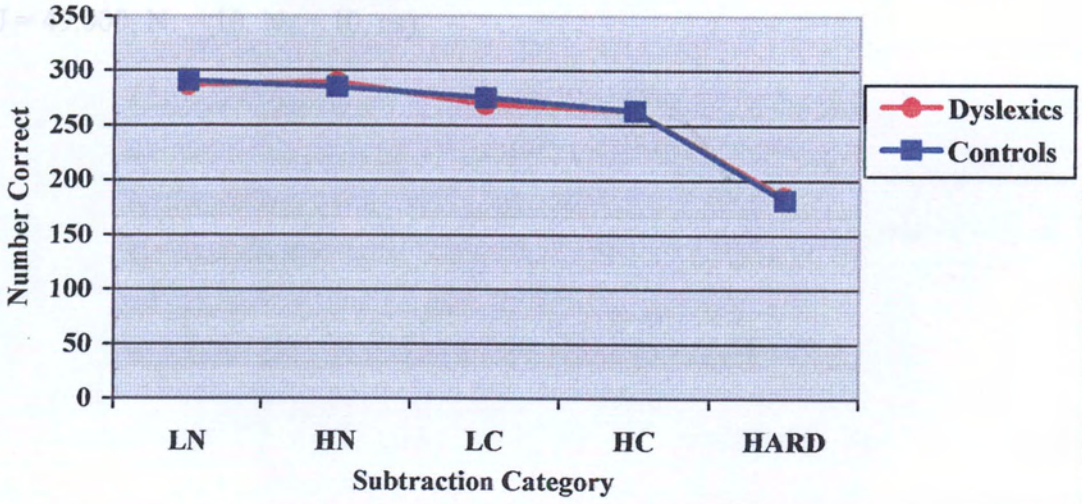
There is a significant difference between dyslexics and non-dyslexics on HARD ($U = 21.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$).

9.3.2 Medium Age Band and the Five Categories

Table 9.3 Number of correct responses made by the dyslexics and non-dyslexics in the medium age band, broken down by category

	Medium age band	
Subtraction category	*Dyslexics*	*Controls*
LN	287	290
HN	289	285
LC	269	275
HC	263	263
HARD	185	182

Figure 9.3 Number of correct responses made by the two groups on subtraction categories - medium age band



Chi-squared = 0.1326, df = 4, ns.

The performance of the dyslexics and controls are significantly similar across all categories.

A non-parametric Mann-Whitney 'U' test showed:

There is no significant difference between dyslexics and non-dyslexics on LN ($U = 45.500$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on HN ($U = 29.500$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on LC ($U = 41.000$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on HC ($U = 48.500$, $N_1 = 10$, $N_2 = 10$, ns).

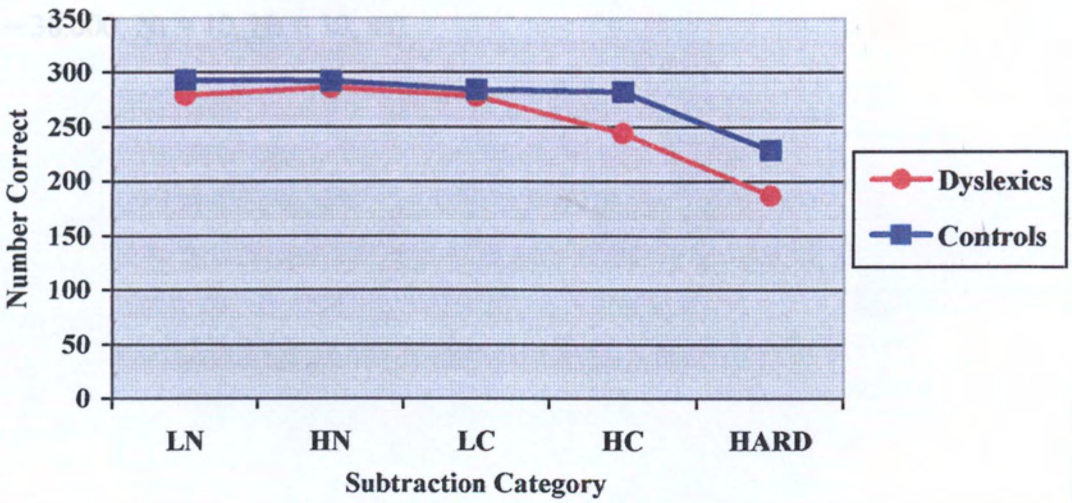
There is no significant difference between dyslexics and non-dyslexics on HARD ($U = 49.000$, $N_1 = 10$, $N_2 = 10$, ns).

9.3.3 Old Age Band and the Five Subtraction Categories

Table 9.4 Number of correct responses made by the dyslexics and non-dyslexics in the old age band, broken down by category

	Old age band	
Subtraction category	*Dyslexics*	*Controls*
LN	279	293
HN	286	292
LC	278	284
HC	244	282
HARD	*187*	228

Figure 9.4 Number of correct responses made by the two groups on subtraction categories - old age band



Chi-squared = 3.114, df = 4, ns.

The performance of the dyslexics and controls are significantly similar across all categories.

A non-parametric Mann-Whitney 'U' test showed:

There is no significant difference between dyslexics and non-dyslexics on LN ($U = 27.000$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on HN ($U = 40.500$, $N_1 = 10$, $N_2 = 10$, ns).

There is no significant difference between dyslexics and non-dyslexics on LC ($U = 44.000$, $N_1 = 10$, $N_2 = 10$, ns).

There is a significant difference between dyslexics and non-dyslexics on HC ($U = 13.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.01$).

There is no significant difference between dyslexics and non-dyslexics on HARD ($U = 38.000$, $N_1 = 10$, $N_2 = 10$, ns).

9.4 Comparing Age Bands Within the Separate Groups

This is illustrated in Figures 9.5 and 9.6.

Figure 9.5 Number of correct responses made by the 3 age bands in the dyslexic group on subtraction tasks

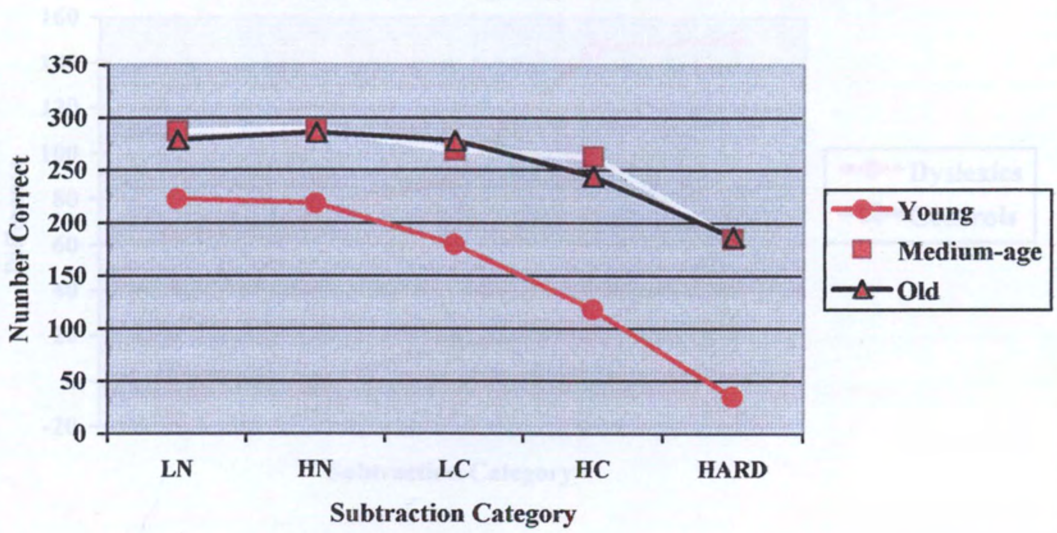
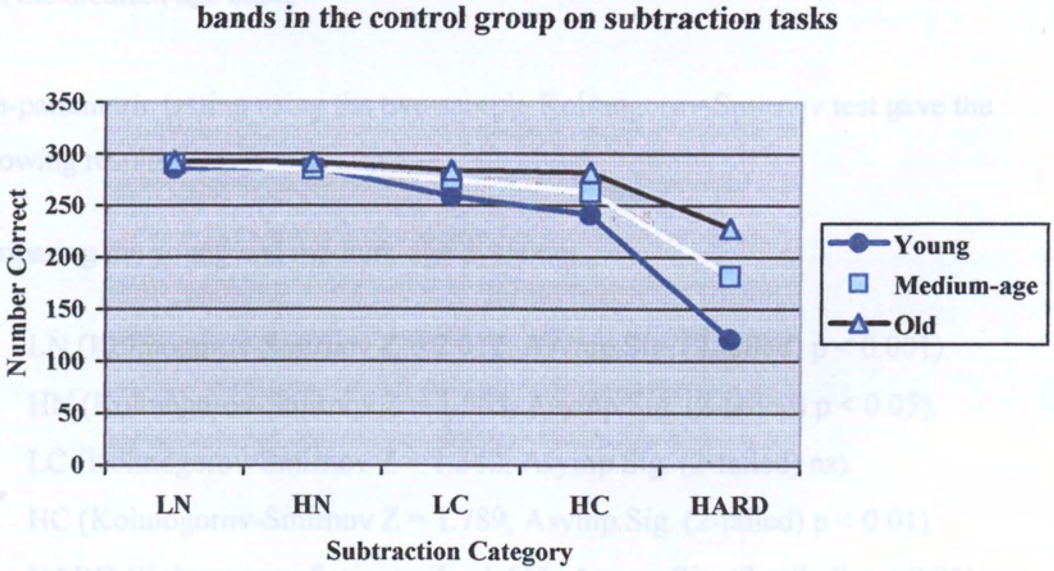
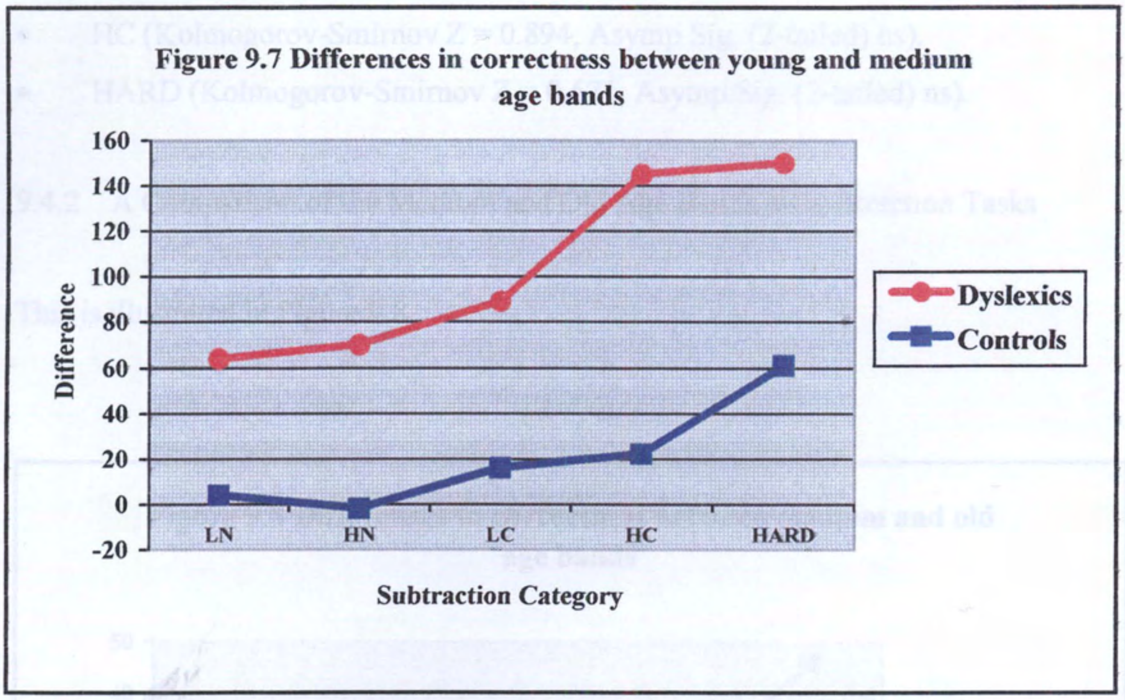


Figure 9.6 Number of correct responses made by the 3 age bands in the control group on subtraction tasks



9.4.1 A Comparison of the Young and Medium Age Bands on Subtraction Tasks

This is illustrated in Figure 9.7.



A negative score indicates that the young age band answered more questions correctly than the medium age band.

Non-parametric testing using the two-sample Kolmogorov-Smirnov test gave the following results:

Comparing the young and medium-age dyslexics

- LN (Kolmogorov-Smirnov $Z = 2.012$, Asymp.Sig. (2-tailed) $p < 0.001$).
- HN (Kolmogorov-Smirnov $Z = 1.565$, Asymp.Sig. (2-tailed) $p < 0.05$).
- LC (Kolmogorov-Smirnov $Z = 1.342$, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov $Z = 1.789$, Asymp.Sig. (2-tailed) $p < 0.01$).
- HARD (Kolmogorov-Smirnov $Z = 1.565$, Asymp.Sig. (2-tailed) $p < 0.05$).

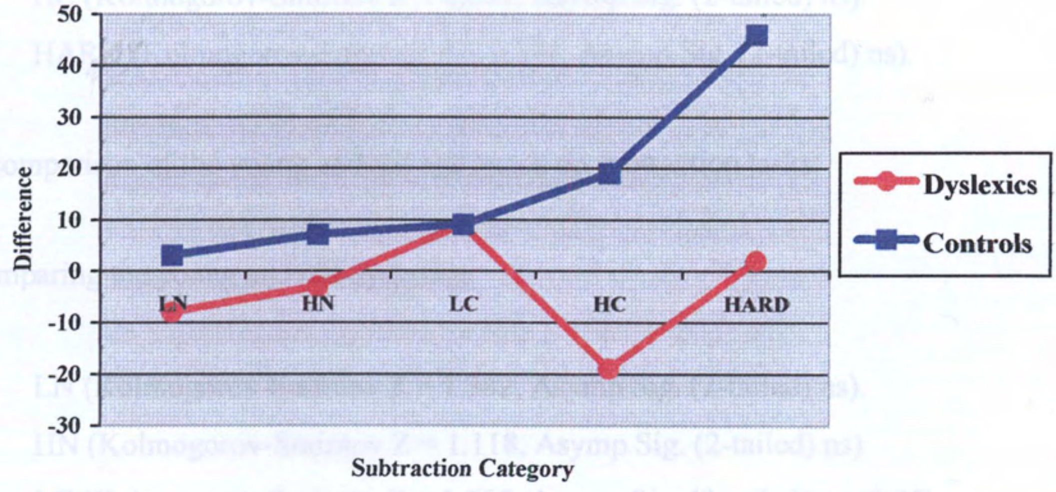
Comparing the young and medium-age controls:

- LN (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 0.894, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).

9.4.2 A Comparison of the Medium and Old Age Bands on Subtraction Tasks

This is illustrated in Figure 9.8.

Figure 9.8 Differences in correctness between medium and old age bands



A negative score indicates that the medium age band answered more questions correctly than the old age band.

Non-parametric testing using the two-sample Kolmogorov-Smirnov test gave the following results:

Comparing the medium-age and old dyslexics

- LN (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 0.447, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 0.224, Asymp.Sig. (2-tailed) ns).

Comparing the medium-age and old controls:

- LN (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 0.894, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov Z = 0.671, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov Z = 0.894, Asymp.Sig. (2-tailed) ns).

A comparison of the young and old age bands on subtraction tasks:

Comparing the young and old dyslexics:

- LN (Kolmogorov-Smirnov Z = 1.342, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov Z = 1.118, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$).
- HC (Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$).
- HARD (Kolmogorov-Smirnov Z = 1.565, Asymp.Sig. (2-tailed) $p < 0.05$).

Comparing the young and old controls:

- LN (Kolmogorov-Smirnov $Z = 0.671$, Asymp.Sig. (2-tailed) ns).
- HN (Kolmogorov-Smirnov $Z = 0.447$, Asymp.Sig. (2-tailed) ns).
- LC (Kolmogorov-Smirnov $Z = 1.118$, Asymp.Sig. (2-tailed) ns).
- HC (Kolmogorov-Smirnov $Z = 1.342$, Asymp.Sig. (2-tailed) ns).
- HARD (Kolmogorov-Smirnov $Z = 1.565$, Asymp.Sig. (2-tailed) $p < 0.05$).

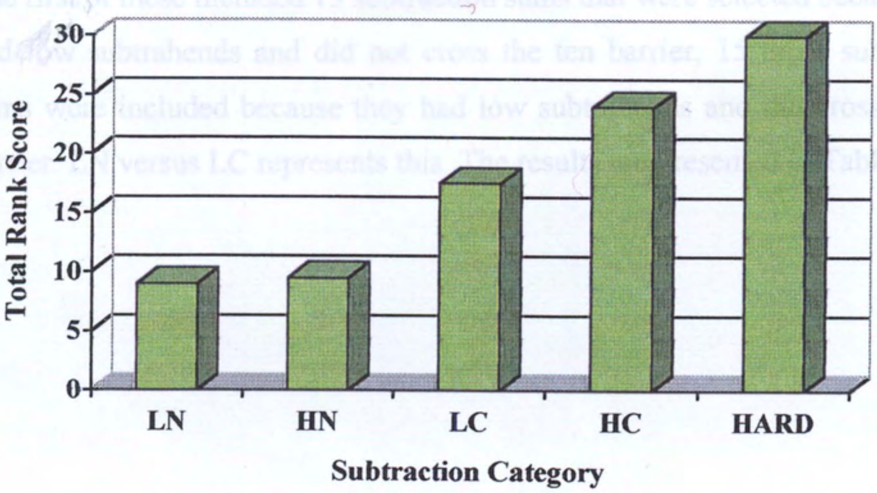
9.5 Order of Difficulty

This chapter is concerned with the number of correct responses given by dyslexics and non-dyslexics in response to subtraction tasks. Table 9.5 shows the rank order of correct responses given on each subtraction category by dyslexics and non-dyslexics in each age band. The ranking begins with the subtraction category answered most correctly. The ranks have been totalled to give a total rank score and an overall rank has been found from this. The results are illustrated in Figure 9.9.

Table 9.5 Order of difficulty for the groups and age bands on subtraction categories

Subtraction category	*Dyslexics*			*Controls*			*Total rank scores*	*Overall rank*
	Age band							
	Young	*Medium-age*	*Old*	*Young*	*Medium-age*	*Old*		
LN	1	1.5	2.5	2	1	1	9	1
HN	2	1.5	1	1	2	2	9.5	2
LC	3	3	2.5	3	3	3	17.5	3
HC	4	4	4	4	4	4	24	4
HARD	5	5	5	5	5	5	30	5

Figure 9.9 Subtraction category total rank scores for all groups and age bands combined



A correlation analysis indicates that there is an overall strong and positive correlation between the orders of difficulty irrespective of group and age band.

Spearman rho = 0.9357, $p < 0.001$.

The order of difficulty on subtraction categories is: LN, HN, LC, HC and HARD.

9.6 Special Number Combinations

Are there any special number combinations for subtraction that are more likely than others to generate errors?

Subtraction has been divided into questions with high/low subtrahends, questions that do and do not cross the ten barrier and finally questions that have a combination of high subtrahends and the need to cross the ten barrier on both the units and tens.

Are dyslexics making extra use of algorithms because of their difficulty in retrieving from memory? If this is so, then in the case of subtraction facts that do not have any obvious algorithm, are dyslexics weaker at producing correct responses than the controls?

Several groupings of 30 or 60 subtraction sums were chosen to test this prediction.

(1) The first of these included 15 subtraction sums that were selected because they had low subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had low subtrahends and did cross the ten barrier. LN versus LC represents this. The results are presented in Table 9.6.

Table 9.6 Number of correct responses by groups and age bands in the LN and LC type condition for subtraction

Groups and age bands	*LN condition*	*LC condition*
Young age band		
Dyslexics	223	180
Controls	286	259
Medium age band		
Dyslexics	287	269
Controls	290	275
Old age band		
Dyslexics	279	278
Controls	293	284

t-Test results on paired samples LN and LC for groups and age bands are as follows:

- Young dyslexics ($t = 1.289$, $df = 9$, ns)
- Young controls ($t = 1.888$, $df = 9$, ns)
- Medium-age dyslexics ($t = 1.662$, $df = 9$, ns)
- Medium-age controls ($t = 2.087$, $df = 9$, ns)
- Old dyslexics ($t = 0.171$, $df = 9$, ns)
- Old controls ($t = 2.077$, $df = 9$, ns)

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band (for which conditions are combined on this test throughout section 9.6) showed:

- Young ($U = 42.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Medium-age ($U = 49.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 42.000$, $N_1 = 10$, $N_2 = 10$, ns)

(2) The second of these included 15 subtraction sums that were selected because they had high subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had high subtrahends and did cross the ten barrier. HN versus HC represents this. The results are presented in Table 9.7.

Table 9.7 Number of correct responses by groups and age bands in the HN and HC type condition for subtraction

Groups and age bands	*HN condition*	*HC condition*
Young age band		
Dyslexics	219	118
Controls	287	241
Medium age band		
Dyslexics	289	263
Controls	285	263
Old age band		
Dyslexics	286	244
Controls	292	282

t-Test results on paired samples HN and HC for groups and age bands are as follows:

- Young dyslexics ($t = 3.017$, $df = 9$, $p < 0.05$)
- Young controls ($t = 3.851$, $df = 9$, $p < 0.01$)
- Medium-age dyslexics ($t = 3.980$, $df = 9$, $p < 0.01$)
- Medium-age controls ($t = 2.606$, $df = 9$, $p < 0.05$)
- Old dyslexics ($t = 2.957$, $df = 9$, $p < 0.05$)
- Old controls ($t = 1.793$, $df = 9$, ns)

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band showed:

- Young (U = 25.500, N_1 = 10, N_2 = 10, ns)
- Medium-age (U = 41.500, N_1 = 10, N_2 = 10, ns)
- Old (U = 26.500, N_1 = 10, N_2 = 10, ns)

(3) The third of these included 15 subtraction sums that were selected because they had low subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had high subtrahends and did not cross the ten barrier. LN versus HN represents this. The results are presented in Table 9.8.

Table 9.8 Number of correct responses by groups and age bands in the LN and HN type condition for subtraction

Groups and age bands	*LN condition*	*HN condition*
Young age band		
Dyslexics	223	219
Controls	286	287
Medium age band		
Dyslexics	287	289
Controls	290	285
Old age band		
Dyslexics	279	286
Controls	293	292

t-Test results on paired samples LN and HN for groups and age bands are as follows:

- Young dyslexics (t = 0.232, df = 9, ns)
- Young controls (t = 0.183, df = 9, ns)
- Medium-age dyslexics (t = 0.408, df = 9, ns)
- Medium-age controls (t = 1.048, df = 9, ns)
- Old dyslexics (t = 1.353, df = 9, ns)
- Old controls (t = 0.198, df = 9, ns)

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band showed:

- Young ($U = 38.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Medium-age ($U = 37.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 35.500$, $N_1 = 10$, $N_2 = 10$, ns)

(4) The fourth of these included 15 subtraction sums that were selected because they had low subtrahends and crossed the ten barrier and 15 other subtraction sums were included because they had high subtrahends and crossed the ten barrier. LC versus HC represents this. The results are presented in Table 9.9.

Table 9.9 Number of correct responses by groups and age bands in the LC and HC type condition for subtraction

Groups and age bands	*LC condition*	*HC condition*
Young age band		
Dyslexics	180	118
Controls	259	241
Medium age band		
Dyslexics	269	263
Controls	275	263
Old age band		
Dyslexics	278	244
Controls	284	282

t-Test results on paired samples LC and HC for groups and age bands are as follows:

- Young dyslexics ($t = 4.627$, $df = 9$, $p < 0.001$)
- Young controls ($t = 1.289$, $df = 9$, ns)
- Medium-age dyslexics ($t = 0.547$, $df = 9$, ns)
- Medium-age controls ($t = 3.284$, $df = 9$, $p < 0.01$)
- Old dyslexics ($t = 4.373$, $df = 9$, $p < 0.01$)
- Old controls ($t = 0.429$, $df = 9$, ns)

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band showed:

- Young ($U = 20.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$)
- Medium-age ($U = 29.500$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 8.000$, $N_1 = 10$, $N_2 = 10$, $p < 0.001$)

(5) The fifth of these included 15 subtraction sums that were selected because they had high subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had low subtrahends and crossed the ten barrier. HN versus LC represents this. The results are presented in Table 9.10.

Table 9.10 Number of correct responses by groups and age bands in the HN and LC type condition for subtraction

Groups and age bands	*HN condition*	*LC condition*
Young age band		
Dyslexics	219	180
Controls	287	259
Medium age band		
Dyslexics	289	269
Controls	285	275
Old age band		
Dyslexics	286	278
Controls	292	284

t-Test results on paired samples HN and LC for groups and age bands are as follows:

- Young dyslexics (t = 1.069, df = 9, ns)
- Young controls (t = 2.201, df = 9, ns)
- Medium-age dyslexics (t = 1.777, df = 9, ns)
- Medium-age controls (t = 1.291, df = 9, ns)
- Old dyslexics (t = 1.018, df = 9, ns)
- Old controls (t = 2.058, df = 9, ns)

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band showed:

- Young (U = 39.000, N_1 = 10, N_2 = 10, ns)
- Medium-age (U = 35.500, N_1 = 10, N_2 = 10, ns)
- Old (U = 47.000, N_1 = 10, N_2 = 10, ns)

(6) The sixth of these included 15 subtraction sums that were selected because they had low subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had high subtrahends, a two-digit number subtracted from a two-digit number and crossed the ten barrier. LN versus HARD represents this. The results are presented in Table 9.11.

Table 9.11 Number of correct responses by groups and age bands in the LN and HARD type condition for subtraction

Groups and age bands	*LN condition*	*HARD condition*
Young age band		
Dyslexics	223	35
Controls	286	121
Medium age band		
Dyslexics	287	185
Controls	290	182
Old age band		
Dyslexics	279	187
Controls	293	228

t-Test results on paired samples LN and HARD for groups and age bands are as follows:

- Young dyslexics $(t = 7.932, df = 9, p < 0.001)$
- Young controls $(t = 4.807, df = 9, p < 0.001)$
- Medium-age dyslexics $(t = 3.422, df = 9, p < 0.01)$
- Medium-age controls $(t = 3.435, df = 9, p < 0.01)$
- Old dyslexics $(t = 3.300, df = 9, p < 0.01)$
- Old controls $(t = 2.867, df = 9, p < 0.05)$

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band showed:

- Young $(U = 49.500, N_1 = 10, N_2 = 10, ns)$
- Medium-age $(U = 48.000, N_1 = 10, N_2 = 10, ns)$
- Old $(U = 41.500, N_1 = 10, N_2 = 10, ns)$

(7) The seventh of these included 30 subtraction sums that were selected because they had low/high subtrahends and did not cross the ten barrier; 30 other subtraction sums were included because they had low/high subtrahends and did cross the ten barrier. LN/HN versus LC/HC represents this. The results are presented in Table 9.12.

Table 9.12 Number of correct responses by groups and age bands in the LN/HN and LC/HC type condition for subtraction

Groups and age bands	*LN/HN condition*	*LC/HC condition*
Young age band		
Dyslexics	442	298
Controls	573	500
Medium age band		
Dyslexics	576	532
Controls	575	538
Old age band		
Dyslexics	565	522
Controls	585	566

t-Test results on paired samples LN/HN and LC/HC for groups and age bands are as follows:

- Young dyslexics ($t = 2.732$, $df = 9$, $p < 0.05$)
- Young controls ($t = 1.230$, $df = 9$, ns)
- Medium-age dyslexics ($t = 0.746$, $df = 9$, ns)
- Medium-age controls ($t = 1.177$, $df = 9$, ns)
- Old dyslexics ($t = 3.567$, $df = 9$, $p < 0.01$)
- Old controls ($t = 0.126$, $df = 9$, ns)

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band showed:

- Young ($U = 30.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Medium-age ($U = 48.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 45.000$, $N_1 = 10$, $N_2 = 10$, ns)

(8) The eighth of these included 30 subtraction sums that were selected because they had low subtrahends which did and did not cross the ten barrier; 30 other subtraction sums were included because they had high subtrahends which did and did not cross the ten barrier. This is represented by LN/LC versus HN/HC. The results are presented in Table 9.13.

Table 9.13 Number of correct responses by groups and age bands in the LN/LC and HN/HC type condition for subtraction

Groups and age bands	*LN/LC condition*	*HN/HC condition*
Young age band		
Dyslexics	403	337
Controls	545	528
Medium age band		
Dyslexics	556	552
Controls	565	548
Old age band		
Dyslexics	557	530
Controls	577	574

t-Test results on paired samples LN/LC and HN/HC for groups and age bands are as follows:

- Young dyslexics ($t = 2.950$, $df = 9$, $p < 0.05$)
- Young controls ($t = 1.170$, $df = 9$, ns)
- Medium-age dyslexics ($t = 0.303$, $df = 9$, ns)
- Medium-age controls ($t = 3.250$, $df = 9$, $p < 0.01$)
- Old dyslexics ($t = 4.150$, $df = 9$, $p < 0.01$)
- Old controls ($t = 0.537$, $df = 9$, ns)

A non-parametric Mann-Whitney 'U' test comparing the two groups in each age band showed:

- Young ($U = 28.500$, $N_1 = 10$, $N_2 = 10$, ns)
- Medium-age ($U = 29.000$, $N_1 = 10$, $N_2 = 10$, ns)
- Old ($U = 18.500$, $N_1 = 10$, $N_2 = 10$, $p < 0.05$)

9.7 Chapter Summary – Questions Answered

Question 1: *Do dyslexics make fewer correct responses than non-dyslexics?*

The answer to this question is 'yes'.

An analysis of variance was conducted on the mean proportion of correct responses made by the groups and age bands. There was an age effect ($p < 0.001$), a group effect ($p < 0.001$) and an age and group effect ($p < 0.001$). Post hoc tests on groups combined showed that there was a significant difference between the young and medium age band ($p < 0.001$) and between the young and old age band ($p < 0.001$) but not between the medium and old age band (ns). Non-parametric tests using Mann-Whitney showed a significant difference between the dyslexics and non-dyslexics in the young age band ($p < 0.01$), but not between the groups in the medium age band. There was at most a marginal significant difference between the dyslexics and controls in the old age band ($p = 0.063$).

A correlation analysis showed that there was an overall strong and positive correlation between the orders of difficulty irrespective of group and age band ($p < 0.001$). The order of difficulty for the categories was: LN, HN, LC, HC and HARD.

Young dyslexics compared to young controls

The young dyslexics answered 52% of subtraction questions correctly compared to 80% by the young controls. The standard deviation was greater for the young dyslexics (0.18) as compared to 0.10 for the young controls. The young dyslexics significantly underpinned the controls across all categories (Chi-squared = 33.038, df = 4, $p < 0.001$). The non-dyslexics were significantly more accurate than the dyslexics on all categories (LN $p < 0.001$, HC $p < 0.001$, HN $p < 0.01$, LC $p < 0.05$ and HARD $p < 0.05$). The dyslexics 'shadowed' the performance of the controls (see Figure 9.2), thus generally if a category was less accurately answered in relation to other categories by the controls, the same was true for the dyslexics. The dyslexics answered the HARD category correctly on 35 out of 300 times compared to 121 times out of a maximum 300 for the controls.

Medium-age dyslexics compared to medium-age controls

No significant differences were found overall or on any of the categories. The results for the two groups were similar as shown by overlapping results illustrated in Figure 9.3.

Old dyslexics compared to old controls

The performance of the dyslexics and controls was significantly similar across the categories (Chi-squared = 3.114, df = 4, ns). On the HC category the non-dyslexics were significantly more accurate than the dyslexics (282 correct responses by the non-dyslexics as compared to 244 for the dyslexics) ($p < 0.01$).

Thus the main effect on the results was the significantly weaker performance of the young dyslexics on all the categories.

Question 2: *Do younger dyslexics make fewer correct responses than older dyslexics?*

Figures 9.5 and 9.6 show the performance of the three age bands per group. The gap between the young dyslexics and the older age bands in the dyslexics group is greater than that found for the non-dyslexics.

Young dyslexics compared to medium-age dyslexics

The medium-age dyslexics were significantly more accurate than the young dyslexics on LN ($p < 0.001$), HC ($p < 0.01$), HN ($p < 0.05$) and HARD ($p < 0.05$). No significant difference was found on the LC category. The difference in correct responses between the young dyslexics and medium-age dyslexics on LN was 64 compared to 4 for the controls. The young controls were significantly similar to the medium-age controls on all categories.

Medium-age dyslexics compared to old dyslexics

No significant differences were found between the medium-age and old dyslexics on any of the categories. Likewise no significant differences were found between the medium-age and old controls on any of the categories. The old controls answered more questions correctly than the medium-age controls on all categories whereas on three out of the five categories (LN, HN, HC) the medium-age dyslexics answered more questions correctly than the old dyslexics.

Young dyslexics compared to old dyslexics

Significant differences between these two age bands in favour of the old dyslexics were found on LC, HC and HARD (all at $p < 0.05$) but not on LN and HN.

A comparison of the young controls with the old controls gave a significant difference on one category – HARD ($p < 0.05$).

Thus the young dyslexics were significantly weaker than the medium-age dyslexics on four out of the five categories. The medium-age dyslexics answered more questions correctly overall than the old dyslexics but the difference between these two age groups was not found to be significant. No significant difference was found between the young dyslexics and the old dyslexics on LN and HN. Yet there had been a significant difference on these two categories between the young and medium-age dyslexics, indicating that the performance of the old dyslexics had decreased in relation to the medium-age dyslexics on LN and HN, whereas the adverse was so on the LC condition.

Question 3: *Are there any special number combinations that are more likely than others to generate errors?*

In order to answer this question, different subtraction categories, independently or in combination, were compared with each other. Only results where a significant difference was found are reported here. The findings on eight comparisons are as follows:

(1) *LN compared to LC.* No significant differences were found between these two conditions for any group age band. No significant difference was found between the groups when these two conditions were combined.

(2) *HN compared to HC.* The young controls and medium-age dyslexics were significantly more accurate on the HN category ($p < 0.01$ for each), as well as the young dyslexics, medium-age controls and old dyslexics ($p < 0.05$ for each).

(3) *LN compared to HN.* No significant differences were found between these two conditions for any group age band. No significant difference was found between the groups when these two conditions were combined.

(4) *LC compared HC.* The young dyslexics ($p < 0.001$), medium-age controls ($p < 0.01$) and the old dyslexics ($p < 0.01$) were significantly less accurate on the HC category. The young controls were significantly more accurate than the young dyslexics and the old controls were significantly more accurate than the old dyslexics on these two conditions combined ($p < 0.05$ and $p < 0.001$ respectively).

(5) *HN compared to LC.* No significant differences were found between these two conditions for any group age band. No significant difference was found between the groups when these two conditions were combined.

(6) *LN compared to HARD.* The young dyslexics and young controls ($p < 0.001$), the medium-age dyslexics, medium-age controls and old dyslexics ($p < 0.01$) and old controls ($p < 0.05$) performed significantly better on the LN category.

(7) *Not crossing (LN and HN combined) compared to crossing (LC and HC combined) the ten barrier.* The young and old dyslexics performed significantly better on the not crossing combination ($p < 0.05$ and $p < 0.01$ respectively).

(8) *Low subtrahends (LN and LC combined) compared to high subtrahends (HN and HC combined).* The young dyslexics ($p < 0.05$), medium-age controls and old dyslexics ($p < 0.01$) performed significantly better on the low subtrahends combination. The old controls were significantly more accurate than the old dyslexics on these combinations combined ($p < 0.05$).

Thus there are special number combinations that are more likely to generate errors than others. On five out of the eight comparisons there was a significant difference between conditions for the young dyslexics; they performed better on the low compared to high subtrahends and on the not crossing compared to the crossing conditions (condition 2, 4, 6, 7 and 8). The medium-age dyslexics performed significantly better on the not crossing condition (HN compared to HC). The old dyslexics were significantly more accurate on low compared to high subtrahends and not crossing compared to crossing conditions (condition 2, 4, 7 and 8). On LC compared to HC (a comparison of low and high subtrahends that crossed the ten barrier) and LN/LC compared to HN/HC (a comparison of the two low subtrahend categories with the two high subtrahend categories) the old dyslexics were significantly less accurate than the old controls when the conditions were combined.

Results of Main Experiments

Speed

CHAPTER 10

Speed of Multiplication

10.1 Aims of This Chapter

10.2 Overall Comparisons

10.3 Tasks Within Multiplication

10.4 Differences Between the Dyslexics and Non-dyslexics on Multiplication

10.5 Comparing Age Bands Within the Separate Groups

10.6 Order of Difficulty

10.7 Topographical Terrains

10.8 Special Number Combinations in Multiplication

10.9 Chapter Summary – Questions Answered

10.1 Aims of This Chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of multiplication:

(1) Do dyslexics need more time than non-dyslexics?

(2) Are younger dyslexics slower than older dyslexics?

(3) Are there any special number combinations which are more likely than others to take more time?

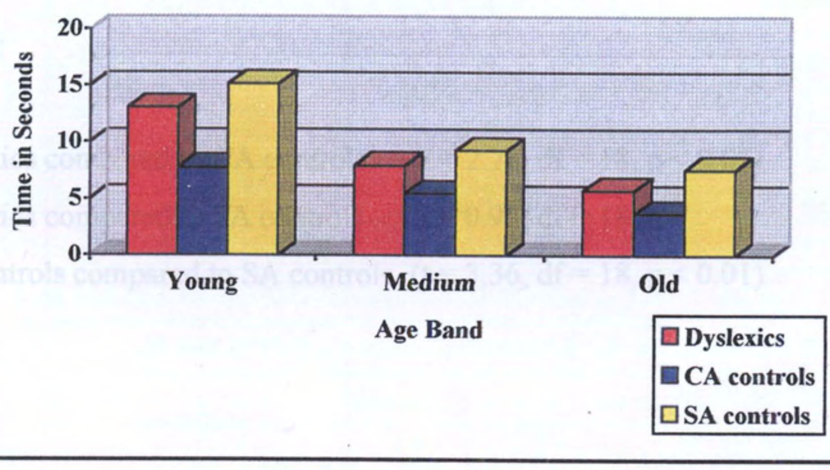
10.2 Overall Comparisons

Each of the experimental groups has been subdivided into three age bands. The results for the mean and median response times and standard deviation for multiplication are given in Table 10.1. The results for the mean response times are illustrated in Figure 10.1.

Table 10.1 Mean times (seconds), standard deviation, median times (seconds) and inter-quartile ranges by group and age on multiplication

Groups	*Age bands*	*Mean*	*Standard deviation*	*Median*	*Inter-quartile ranges*
Dyslexics	Young	13.02	3.04	5.97	4.19–9.93
	Medium	7.93	2.60	4.03	2.76–6.57
	Old	5.77	1.16	2.65	1.97–4.17
CA controls	Young	7.75	1.89	4.17	2.98–6.46
	Medium	5.45	1.11	3.01	2.24–4.53
	Old	3.70	0.62	2.13	1.74–2.90
SA controls	Young	15.14	3.83	6.79	4.71–9.84
	Medium	9.24	3.39	4.59	3.20–6.96
	Old	7.61	1.77	3.88	2.90–5.73

Figure 10.1 Mean response time by group and age on multiplication



Analysis of variance for the mean data show the following overall results:

There is a significant main effect between groups ($F(2,81) = 33.88$, $p < 0.001$).
There is a significant main effect between age bands ($F(2,81) = 54.07$, $p < 0.001$).
There is no significant interaction between group and age ($F(4,81) = 2.14$, ns).

Analysis of variance tables are presented in Appendix F5.

Post hoc tests (Tamhane) show that there is a significant difference ($p < 0.001$) between the groups except for a non-significant difference between the dyslexics and the SA controls. There is a significant difference ($p < 0.001$) between the young and medium age band, the young and old age band and the medium-age and old age band ($p < 0.02$).

t-Tests comparing the groups in each age band show:

Young:

- Dyslexics compared to CA controls ($t = 4.65$, $df = 18$, $p < 0.001$)
- Dyslexics compared to SA controls ($t = 1.37$, $df = 18$, ns)
- CA controls compared to SA controls ($t = 5.47$, $df = 18$, $p < 0.001$)

Medium-age:

- Dyslexics compared to CA controls ($t = 2.76$, $df = 18$, $p < 0.05$)
- Dyslexics compared to SA controls ($t = 0.97$, $df = 18$, ns)
- CA controls compared to SA controls ($t = 3.36$, $df = 18$, $p < 0.01$)

Old:

- Dyslexics compared to CA controls ($t = 4.98$, $df = 18$, $p < 0.001$)
- Dyslexics compared to SA controls ($t = 2.76$, $df = 18$, $p < 0.05$)
- CA controls compared to SA controls ($t = 6.58$, $df = 18$, $p < 0.001$)

10.3 Tasks Within Multiplication

Multiplication can be broken down into various tasks. Twelve multiplication tables were chosen ranging from the 1 to the 12 times table. The multiplication table number was taken as the multiplicand in each question. Speed of response by participants was recorded for group, age and multiplication table. Results of analysis of variance are shown in Table 10.2.

Table 10.2 Analysis of variance results (between-subjects effects) showing significant differences in mean response times between groups, age bands and the intercept of groups and age bands

Multiplication table	*Groups*	*Age bands*	*Group and age band*
1	85.689***	128.210***	17.988***
2	129.643***	272.564***	16.838***
3	152.164***	202.905***	7.068***
4	137.297***	200.526***	7.885***
5	111.311***	193.379***	12.338***
6	132.364***	181.275***	4.558***
7	131.056***	157.512***	8.191***
8	137.009***	180.182***	3.115*
9	122.319***	199.282***	4.058**
10	86.746***	218.053***	16.417***
11	98.666***	175.056***	18.159***
12	94.889***	176.313***	6.517***
	F (2,2151)	F (2,2151)	F (4,2151)

Significance levels key:

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

Post hoc (Tamhane) tests show a significant difference ($p < 0.001$) between groups and also age bands for all multiplication tables except the following:

Between dyslexics and SA controls $p < 0.01$ on the 7 and 9 multiplication tables and $p < 0.05$ on the 12 multiplication table.

The results are given for each age band in turn in Tables 10.3, 10.4 and 10.5 and these are illustrated in Figures 10.2, 10.3 and 10.4.

Table 10.3 Mean response time (in seconds) for each multiplication table by group in the young age band (standard deviation in brackets)

Multiplication table	*Young age band*		
	Dyslexics	*CA controls*	*SA controls*
1	6.25 (0.82)	3.82 (0.83)	9.67 (1.32)
2	9.63 (2.47)	5.76 (1.61)	13.07 (2.78)
3	12.53 (4.11)	6.83 (2.69)	14.29 (3.91)
4	13.17 (5.08)	7.82 (3.21)	15.83 (3.13)
5	11.19 (3.48)	6.58 (1.76)	14.22 (3.30)
6	14.72 (4.98)	9.15 (3.95)	16.60 (3.85)
7	15.78 (5.23)	8.65 (3.28)	17.13 (3.97)
8	16.42 (5.69)	10.61 (4.55)	17.36 (4.49)
9	16.42 (5.46)	10.22 (4.22)	17.21 (4.08)
10	9.21 (3.68)	5.32 (2.32)	11.61 (3.53)
11	13.32 (4.61)	6.96 (4.52)	16.14 (3.13)
12	17.56 (4.79)	11.23 (3.55)	18.52 (3.39)

Figure 10.2 Mean response time for each multiplication table by group and young age band

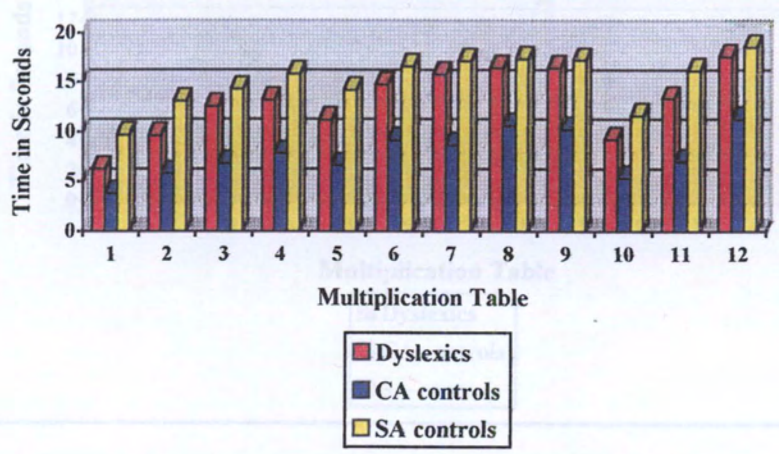


Table 10.4 Mean response time (in seconds) for each multiplication table by group in the medium age band (standard deviation in brackets)

Multiplication table	*Medium age band*		
	Dyslexics	*CA controls*	*SA controls*
1	4.31 (1.00)	2.74 (0.74)	4.72 (0.88)
2	5.19 (0.72)	3.28 (0.67)	6.31 (1.40)
3	6.84 (2.90)	4.37 (1.63)	8.98 (3.28)
4	8.17 (3.57)	5.37 (2.51)	8.96 (2.63)
5	6.41 (2.36)	4.64 (1.86)	7.92 (1.98)
6	9.21 (3.84)	6.85 (3.28)	11.25 (3.58)
7	9.96 (4.95)	6.44 (2.87)	11.22 (4.62)
8	10.70 (4.83)	7.01 (2.80)	12.58 (4.78)
9	10.33 (4.30)	6.56 (2.82)	11.50 (3.91)
10	5.34 (1.91)	3.76 (2.04)	5.75 (1.97)
11	7.26 (4.56)	5.83 (4.85)	9.68 (4.50)
12	11.43 (4.54)	8.60 (3.26)	12.01 (4.10)

Figure 10.3 Mean response time for each multiplication table by group and medium age band

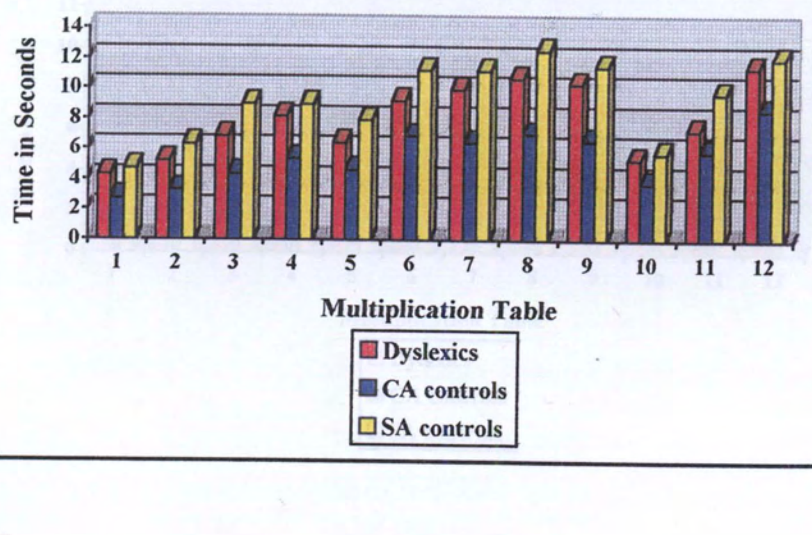
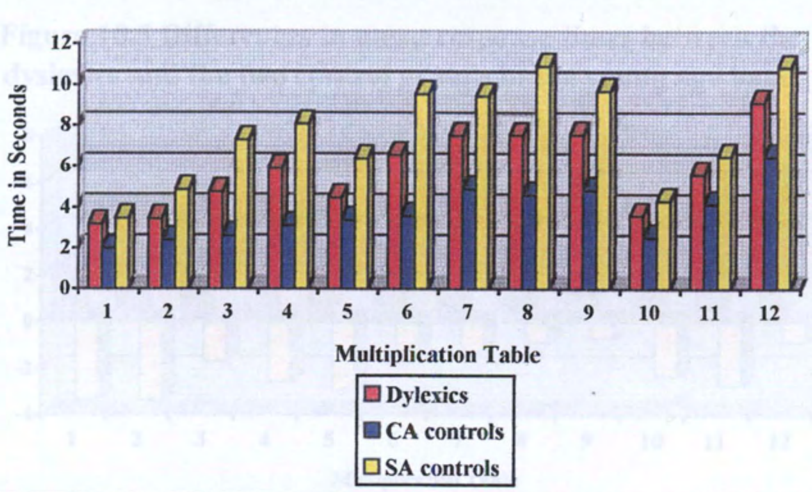


Table 10.5 Mean response time (in seconds) for each multiplication table by group in the old age band (standard deviation in brackets)

Multiplication table	*Old age band*		
	Dyslexics	*CA controls*	*SA controls*
1	3.18 (1.02)	1.98 (0.54)	3.48 (0.65)
2	3.44 (0.94)	2.40 (0.59)	4.87 (0.74)
3	4.75 (1.74)	2.60 (0.96)	7.30 (3.79)
4	5.90 (3.41)	3.10 (1.55)	8.09 (3.94)
5	4.46 (1.83)	3.36 (1.53)	6.39 (2.73)
6	6.55 (3.29)	3.57 (1.62)	9.55 (4.69)
7	7.50 (4.25)	4.88 (2.56)	9.44 (4.45)
8	7.52 (3.44)	4.59 (2.69)	10.90 (4.81)
9	7.57 (4.19)	4.84 (2.57)	9.71 (4.19)
10	3.59 (1.45)	2.52 (0.59)	4.31 (1.50)
11	5.60 (4.91)	4.16 (3.50)	6.49 (4.08)
12	9.13 (4.22)	6.45 (2.89)	10.82 (3.95)

Figure 10.4 Mean response time for each multiplication table by group and old age band



10.4 Differences Between the Dyslexics and Non-dyslexics on Multiplication

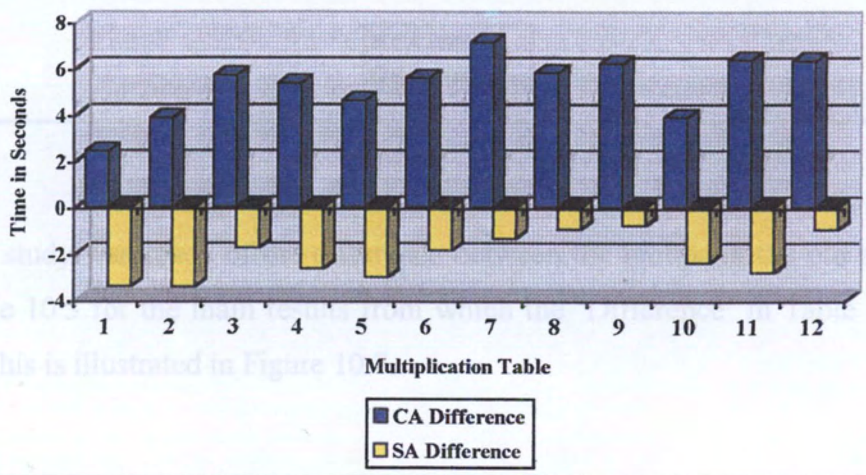
The information in this section does not display new data but draws on the results found in section 10.3. This section enables the reader to analyse the differences found in the mean times between the two experimental groups. A negative score in Tables 10.6, 10.7 and 10.8 indicates that a mean response time was slower than that of the dyslexic group.

Firstly a study was made of the difference between the groups in the young age band. (See Table 10.3 for the main results from which the 'Difference' in Table 10.6 was drawn.) The results are illustrated in Figure 10.5.

Table 10.6 Differences in mean response times (in seconds) between the dyslexics and the two control groups in the young age band

	Multiplication table											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
CA difference	2.43	3.87	5.7	5.35	4.61	5.57	7.13	5.81	6.2	3.89	6.36	6.33
SA difference	−3.42	−3.44	−1.76	−2.66	−3.03	−1.88	−1.35	−0.94	−0.79	−2.4	−2.82	−0.96

Figure 10.5 Differences in mean response times between the dyslexics and the two control groups in the young age band

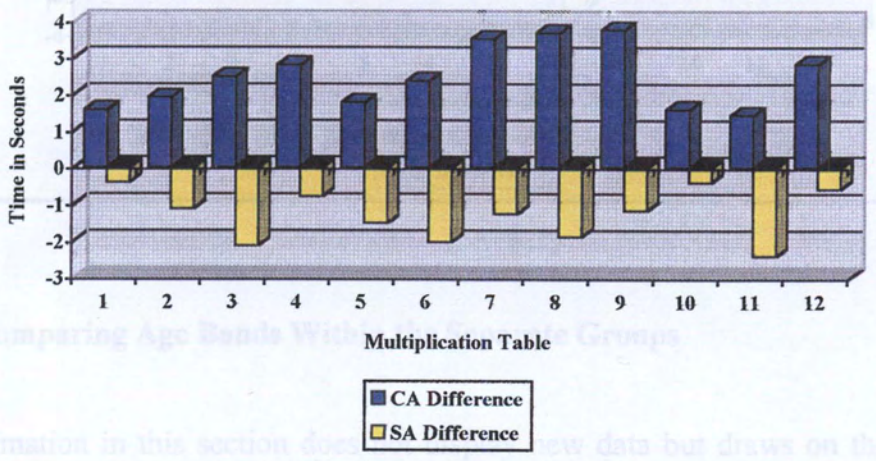


Secondly a study was made of the difference between the groups in the medium age band. Please refer to Table 10.4 for the main results from which the 'Difference' in Table 10.7 was drawn. The results are illustrated in Figure 10.6.

Table 10.7 Differences in mean response times (in seconds) between the dyslexics and the two control groups in the medium age band

	Multiplication table											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
CA difference	1.57	1.91	2.47	2.8	1.77	2.36	3.52	3.69	3.77	1.58	1.43	2.83
SA difference	–0.41	–1.12	–2.14	–0.79	–1.51	–2.04	–1.26	–1.88	–1.17	–0.41	–2.42	–0.58

Figure 10.6 Differences in mean response times between the dyslexics and the two control groups in the medium age band

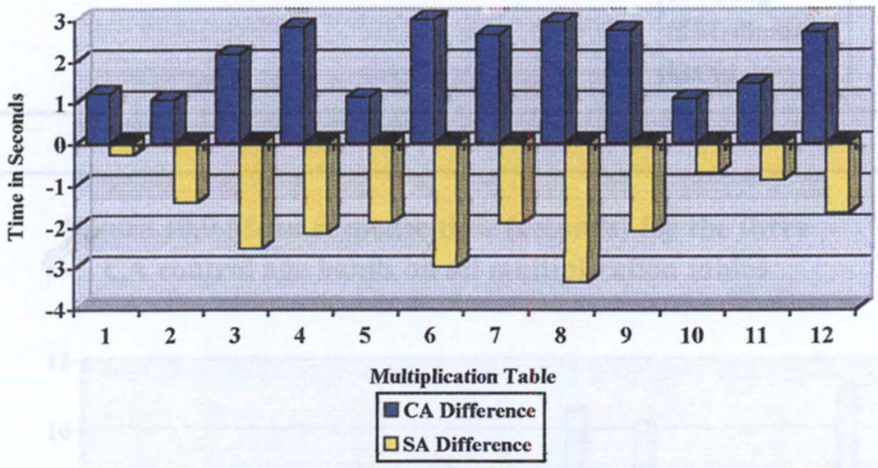


Thirdly a study was made of the difference between the groups in the old age band. (See Table 10.5 for the main results from which the 'Difference' in Table 10.8 was drawn.) This is illustrated in Figure 10.7.

Table 10.8 Differences in mean response times (in seconds) between the dyslexic and the two control groups in the old age band

	Multiplication table											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
CA difference	1.2	1.04	2.15	2.8	1.1	2.98	2.62	2.93	2.73	1.07	1.44	2.68
SA difference	-0.3	-1.43	-2.55	-2.19	-1.93	-3.00	-1.94	-3.38	-2.14	-0.72	-0.89	-1.69

Figure 10.7 Differences in mean response times between the dyslexics and the two control groups in the old age band



10.5 Comparing Age Bands Within the Separate Groups

The information in this section does not display new data but draws on the results found in section 10.3. This section enables the reader to compare age band performance within the separate groups. The results are illustrated in Figures 10.8, 10.9 and 10.10 for each group in turn.

Figure 10.8 Mean response time (seconds) for the three dyslexic age bands on all multiplication tables

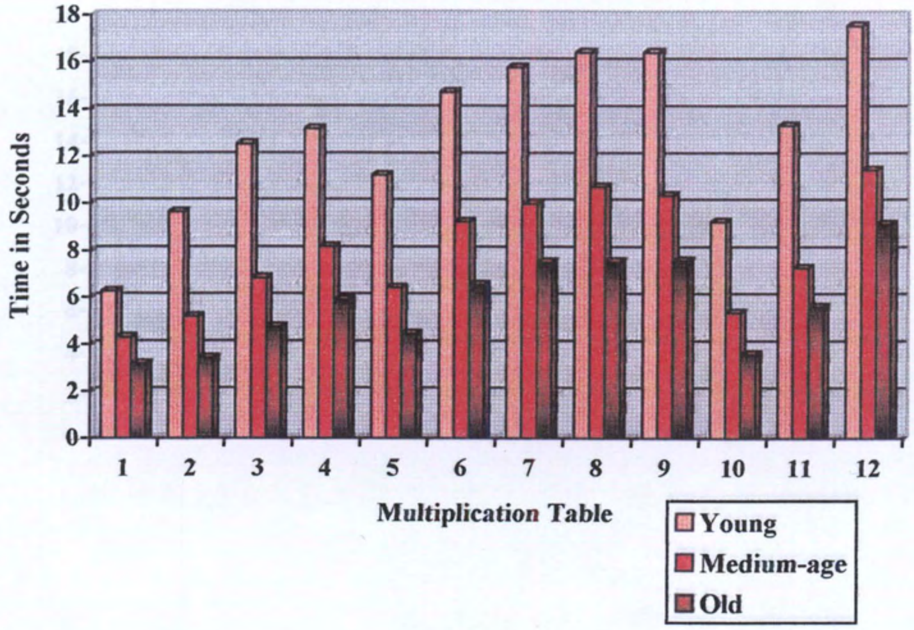


Figure 10.9 Mean response time (seconds) for the three CA control age bands on all multiplication tables

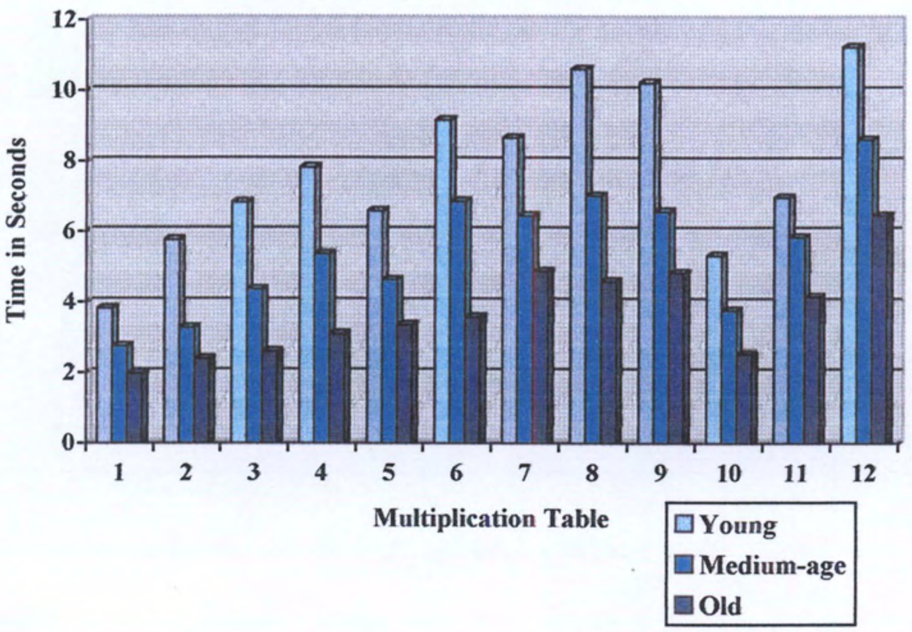
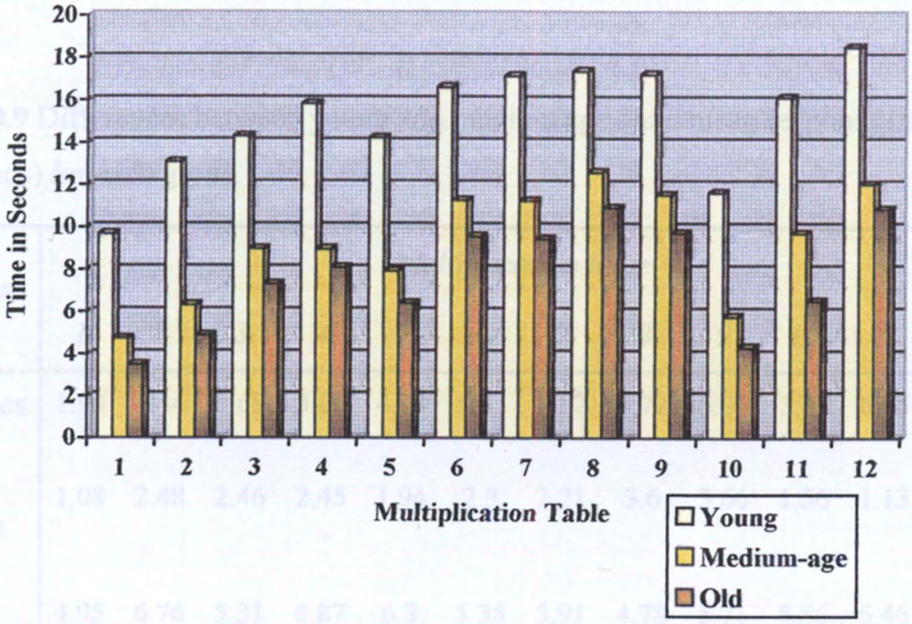


Figure 10.10 Mean response time (seconds) for the three SA control age bands on all multiplication tables



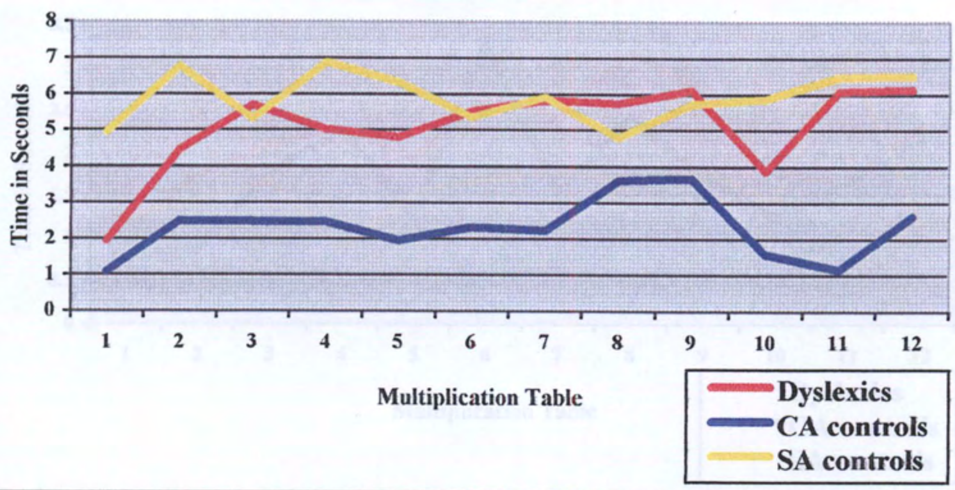
10.5.1 Comparison of the Young and Medium Age Bands on Multiplication Tasks

The results are presented in Table 10.9 and Figure 10.11.

Table 10.9 Differences between young and medium age band mean response times (in seconds) for each group

Groups	*Multiplication table*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Dyslexics	1.94	4.44	5.69	5.00	4.78	5.51	5.82	5.72	6.09	3.87	6.06	6.13
CA controls	1.08	2.48	2.46	2.45	1.94	2.3	2.21	3.6	3.66	1.56	1.13	2.63
SA controls	4.95	6.76	5.31	6.87	6.3	5.35	5.91	4.78	5.71	5.86	6.46	6.51

Figure 10.11 Differences between young and medium age band mean response times



t-Tests comparing the young and medium age bands in each group show:

- Dyslexics (t = 26.005, df = 5758, p < 0.001)
- CA controls (t = 13.992, df = 5758, p < 0.001)
- SA controls (t = 29.629, df = 5758, p < 0.001)

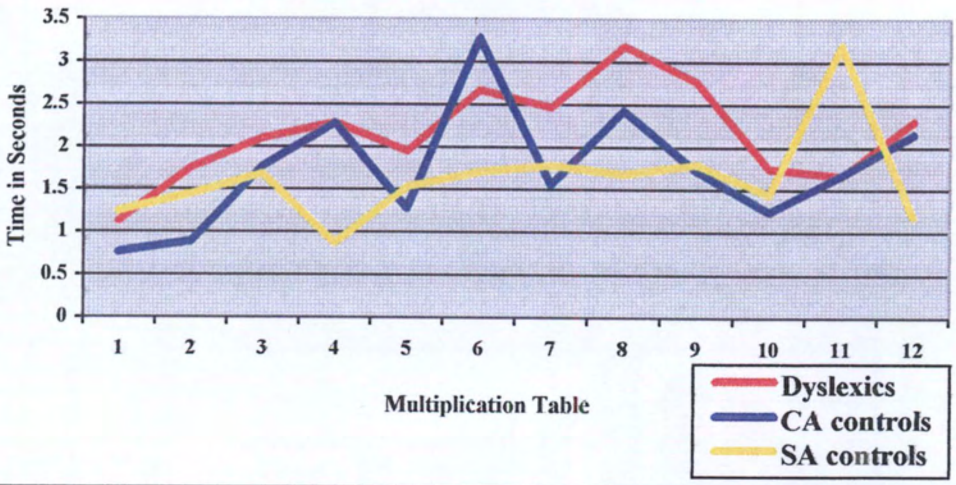
10.5.2 Comparison of the Medium and Old Age Bands on Multiplication Tasks

The results are presented in Table 10.10 and Figure 10.12.

Table 10.10 Differences between medium and old age band mean response times (in seconds) for each group

Groups	*Multiplication table*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Dyslexics	1.13	1.75	2.09	2.27	1.95	2.66	2.46	3.18	2.76	1.75	1.66	2.3
CA controls	0.76	0.88	1.77	2.27	1.28	3.28	1.56	2.42	1.72	1.24	1.67	2.15
SA controls	1.24	1.44	1.68	0.87	1.53	1.70	1.78	1.68	1.79	1.44	3.19	1.19

Figure 10.12 Differences between the medium and old age band mean response times



t-Tests comparing the medium and old age bands in each group show:

- Dyslexics (t = 12.207, df = 5758, p < 0.001)
- CA controls (t = 12.746, df = 5758, p < 0.001)
- SA controls (t = 8.627, df = 5758, p < 0.001)

t-Tests comparing the young and old age bands in each group show:

- Dyslexics ($t = 38.253$, $df = 5758$, $p < 0.001$)
- CA controls ($t = 26.494$, $df = 5758$, $p < 0.001$)
- SA controls ($t = 39.212$, $df = 5758$, $p < 0.001$)

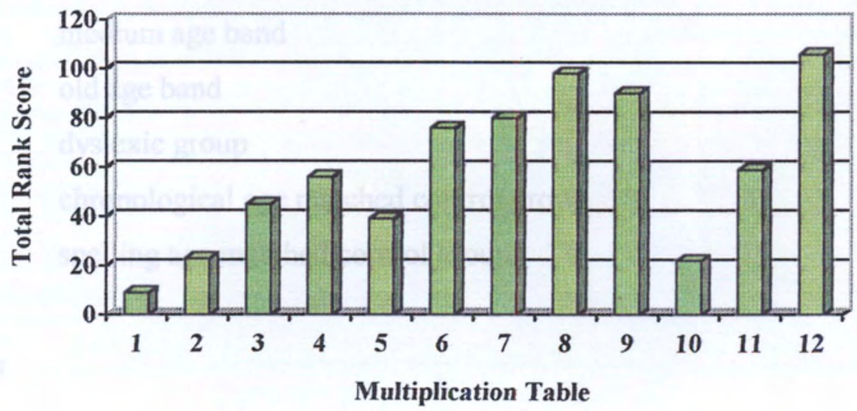
10.6 Order of Difficulty

The results displayed in Tables 10.3, 10.4 and 10.5 show the mean response times for groups and age bands on each multiplication table ('times table'). Table 10.11 shows the rank order of difficulty of the multiplication tables for each group and age band (Y = young, M = medium-age, O = old) found from these tables. The ranks have been totalled and the 'overall rank' found from these. The results are illustrated in Figure 10.13.

Table 10.11 Order of difficulty for the 12 multiplication tables

Times table	*Dyslexics*			*CA controls*			*SA controls*			*Total rank score*	*Overall rank*
	Age bands										
	Y	*M*	*O*	*Y*	*M*	*O*	*Y*	*M*	*O*		
1	1	1	1	1	1	1	1	1	1	9	1
2	3	2	2	3	2	2	3	3	3	23	3
3	5	5	5	5	4	4	5	6	6	45	5
4	6	7	7	7	6	5	6	5	7	56	6
5	4	4	4	4	5	6	4	4	4	39	4
6	8	8	8	9	10	7	8	9	9	76	8
7	9	9	9	8	9	11	9	8	8	80	9
8	11	11	10	11	11	9	11	12	12	98	11
9	11	10	11	10	8	10	10	10	10	90	10
10	2	3	3	2	3	3	2	2	2	22	2
11	7	6	6	6	7	8	7	7	5	59	7
12	12	12	12	12	12	12	12	11	11	106	12

Figure 10.13 Multiplication table total rank scores on speed for all groups and age bands combined



The results of non-parametric correlations on the order of difficulty by group and age band are given in Table 10.12.

Table 10.12 Non-parametric correlations using Spearman's rho on order of difficulty in multiplication

	MD	*OD*	*YCA*	*MCA*	*OCA*	*YSA*	*MSA*	*OSA*	*Overall rank*
YD	0.986**	0.944**	0.902**	0.810**	0.908**	0.958**	0.944**	0.949**	0.972**
MD		0.944**	0.923**	0.803**	0.916**	0.979**	0.958**	0.939**	0.979**
OD			0.860**	0.768**	0.908**	0.930**	0.902**	0.928**	0.937**
YCA				0.768**	0.831**	0.902**	0.923**	0.925**	0.951**
MCA					0.851**	0.817**	0.718**	0.684*	0.789**
OCA						0.916**	0.901**	0.836**	0.930**
YSA							0.937**	0.928**	0.958**
MSA								0.946**	0.986**
OSA									0.960**

Key:

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Y = young age band

M = medium age band

O = old age band

D = dyslexic group

CA = chronological age matched control group

SA = spelling age matched control group

Discussion

If the criterion is speed of performing multiplication, the order of difficulty for the multiplication tables is: 1, 10, 2, 5, 3, 4, 11, 6, 7, 9, 8 and 12.

For multiplication, tables are easier:

(1) if the multiplicand is small, and

(2) if, as in the case of 5×, 10× and 11×, there is a rule or algorithm readily available.

10.7 Topographical Terrains

Topographical terrain presentation is a visual way of showing the level of ease or difficulty encountered when group and age band participants tackle particular multiplication tables. The nine terrains given in Figures 10.14 to 10.22 have been colour coded according to mean correct response time in seconds. The terrain is designed to reflect the 12 × 12 multiplication grid presented in a three-dimensional form. The dimensions represented are the multiplicand, multiplier and mean response time. The higher the terrain, the longer the response time and ultimately the harder the multiplication question.

Figure 10.14 Mean response time for the young dyslexics on multiplication

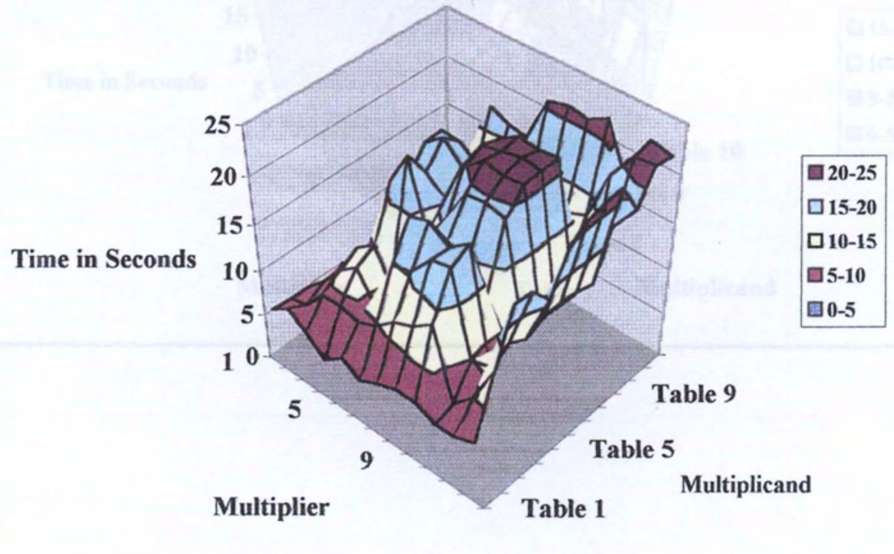


Figure 10.15 Mean response time for the medium-age dyslexics on multiplication

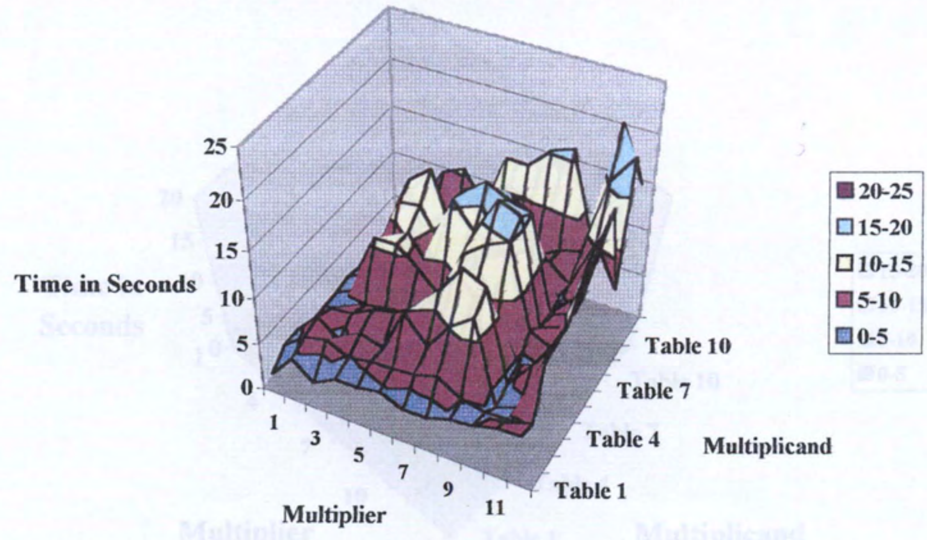


Figure 10.16 Mean response time for the old dyslexics on multiplication

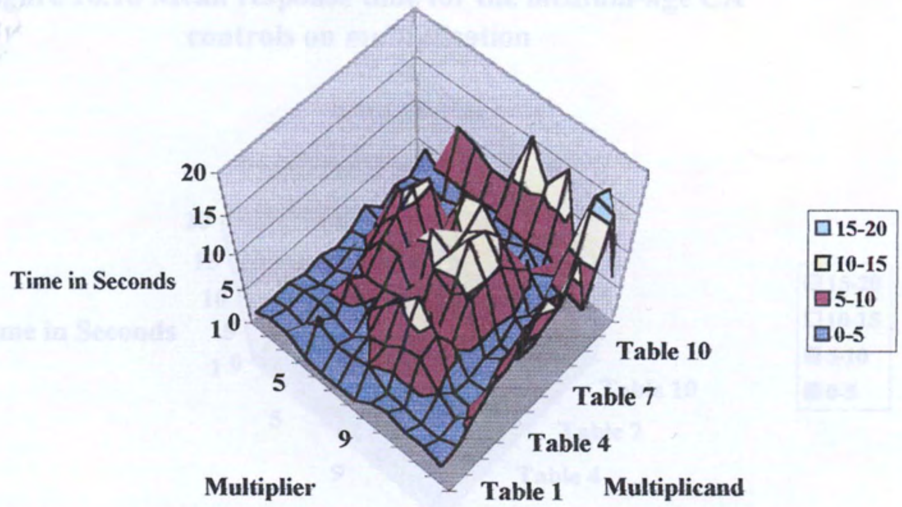


Figure 10.17 Mean response time for the young CA controls on multiplication

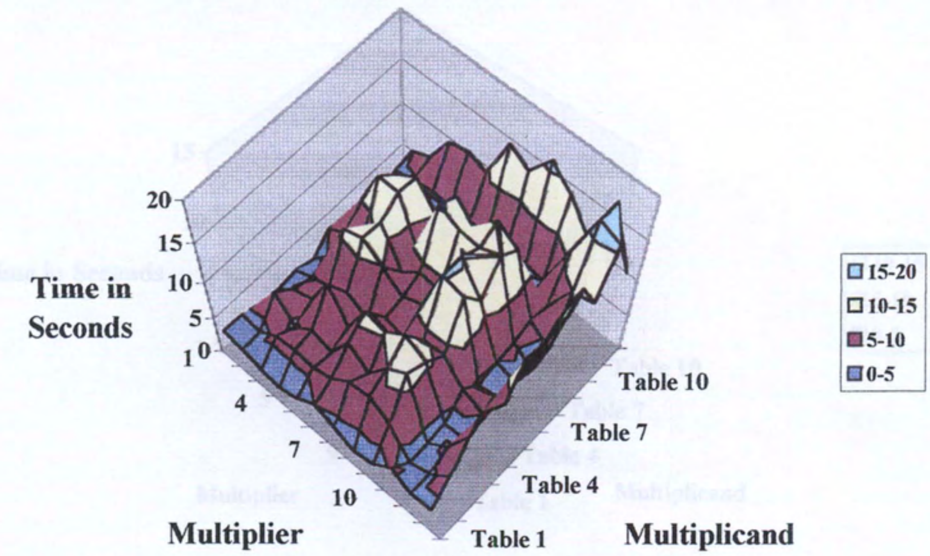


Figure 10.18 Mean response time for the medium-age CA controls on multiplication

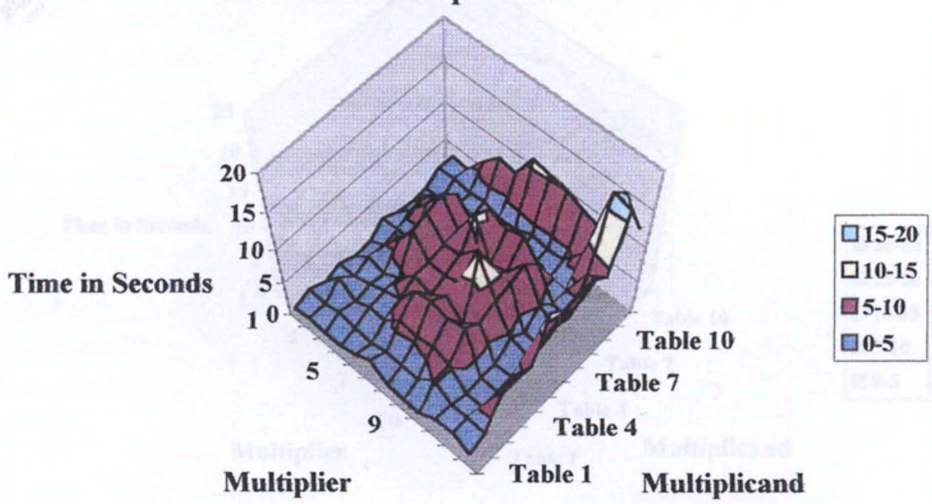


Figure 10.19 Mean response time for the old CA controls on multiplication

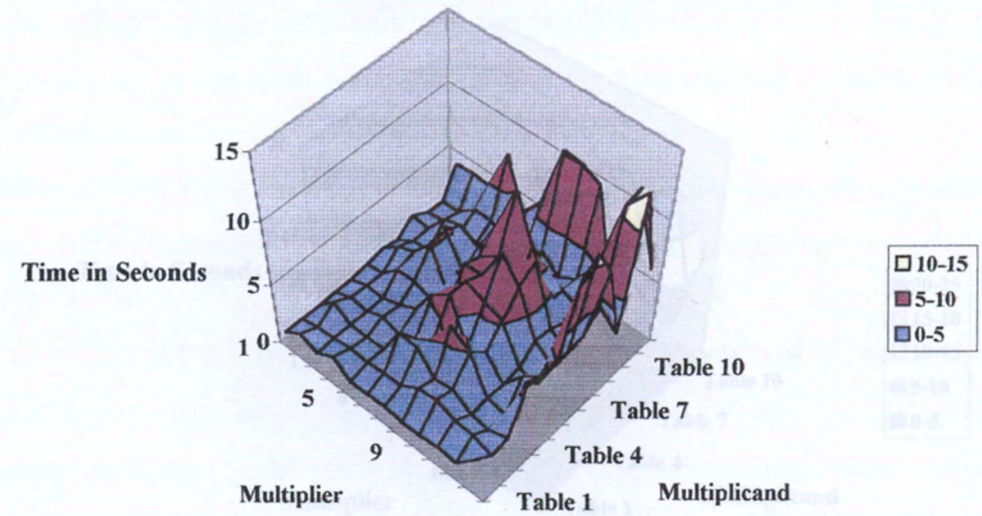


Figure 10.20 Mean response time for the young SA controls on multiplication

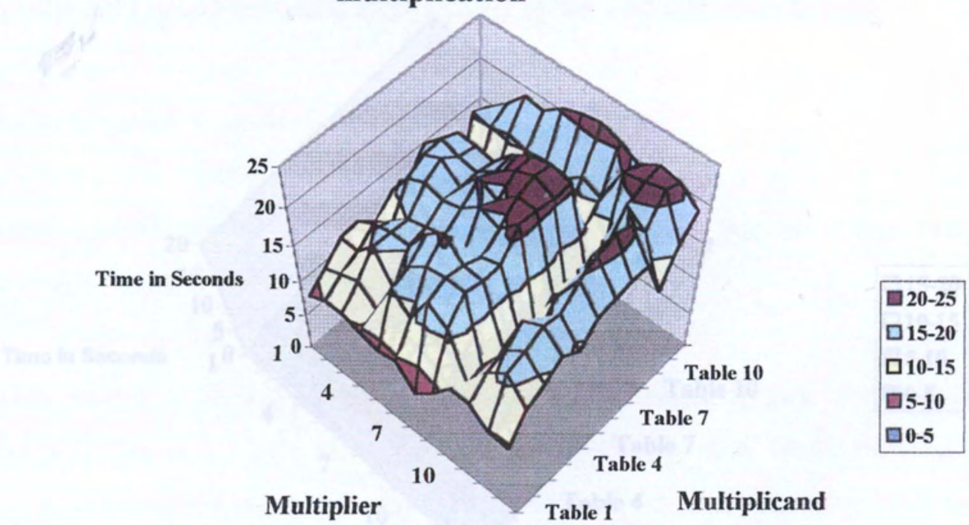


Figure 10.21 Mean response time for the medium-age SA controls on multiplication

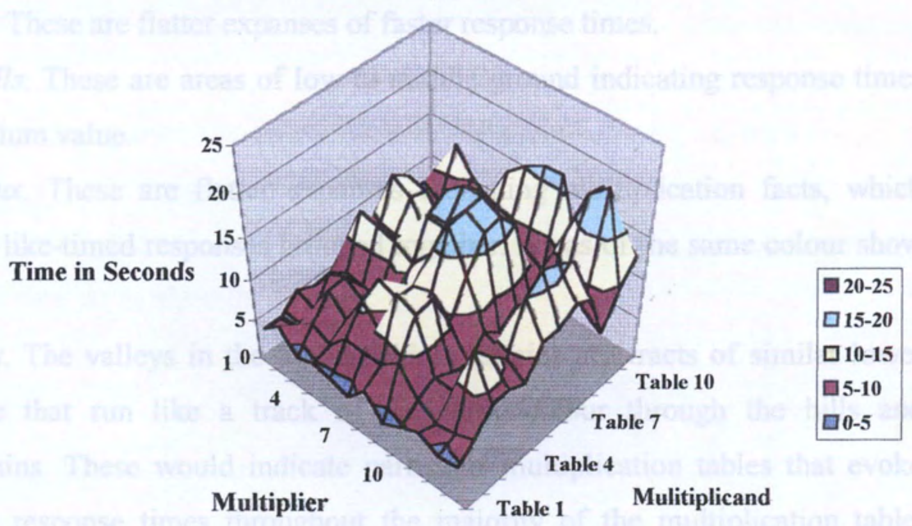
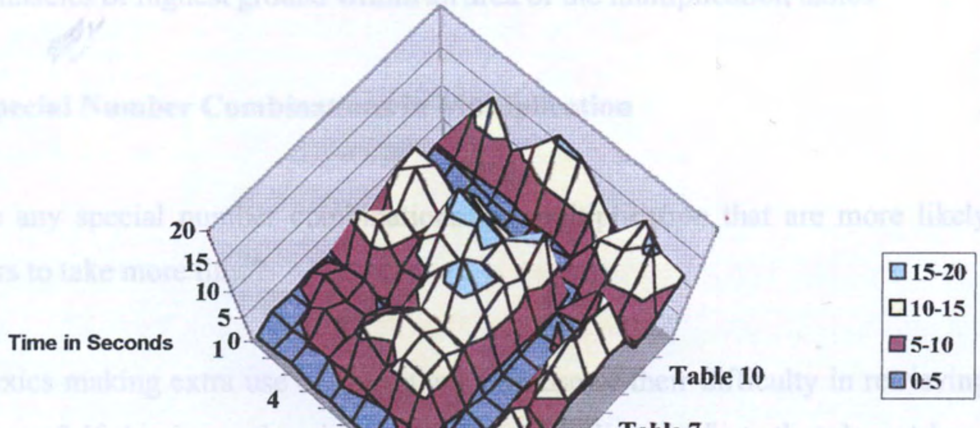


Figure 10.22 Mean response time for the old SA controls on multiplication



The terrains have the following properties:

(1) *Colour*. The colour-coding key indicates the time span within which the response is given. Times given in the coding do not overlap. This coding is

consistent across groups and age bands. From quickest to slowest response times the colours are: blue, maroon, yellow, aquamarine and purple.

(2) *Plains*. These are flatter expanses of faster response times.

(3) *Foothills*. These are areas of low to middle ground indicating response times of medium value.

(4) *Plateaux*. These are flatter expanses indicating multiplication facts, which gained like-timed responses grouped together. Areas of the same colour show these.

(5) *Valleys*. The valleys in the topographical terrains are tracts of similar lower altitude that run like a track of the same colour through the hills and mountains. These would indicate particular multiplication tables that evoke similar response times throughout the majority of the multiplication table, such as the 10× table. The valley stands out because it is bordered by higher land on either side. Here the adjoining multiplication tables would take the participants longer to answer.

(6) *Mountain peaks*. Peaks indicate a sudden climb of difficulty shown by sharp pinnacles of highest ground within an area of the multiplication tables.

10.8 Special Number Combinations in Multiplication

Are there any special number combinations for multiplication that are more likely than others to take more time?

Are dyslexics making extra use of algorithms because of their difficulty in retrieving from memory? If this is so, then in the case of multiplication facts that do not have any obvious algorithm, are dyslexics slower at producing correct responses than the CA controls?

Sixteen multiplication sums were chosen to test this prediction: 8 of these were selected because they had well known algorithms ('X-type' questions) and 8 other multiplication sums were included because they did not have an obvious algorithm ('Y-type' questions).

Selection of questions was based on the following:

(1) no multiplicand or multiplier less than 6 on the basis of the question being too easy;

(2) no product being over 100 on the basis of the question being too hard.

'X-type' questions included sums from the 10× and 11× tables, which have well known patterns serving as algorithms.

'Y-type' questions were chosen from the 7× and 8× tables since they have no clear algorithms for the participants to employ.

The multiplication sums that were selected therefore included 7, 8, 10 and 11 as the multiplicand and 6, 7, 8 and 9 as the multiplier.

The 'X-type' sums were:	$10 \times 6, 10 \times 7, 10 \times 8, 10 \times 9$
	$11 \times 6, 11 \times 7, 11 \times 8, 11 \times 9$
The 'Y-type' sums were:	$7 \times 6, 7 \times 7, 7 \times 8, 7 \times 9$
	$8 \times 6, 8 \times 7, 8 \times 8, 8 \times 9$

Each multiplication sum was presented twice to each participant and thus there were results for 16 'X-type' and 16 'Y-type' multiplication sums. Table 10.13 shows the median response times and Table 10.14 shows the mean response times made by each group/age band on the 'X' and 'Y' type condition. Figure 10.23 illustrates the latter.

An 'M' is used after 'X' and 'Y' to denote multiplication.

Table 10.13 Median times (seconds) for the three groups and the three age bands in the 'X_M' condition and 'Y_M' condition for multiplication

Groups and age bands	*'X_M' condition*	*'Y_M' condition*
Young age band		
Dyslexics	5.65	14.15
CA controls	3.68	6.75
SA controls	6.09	8.34
Medium age band		
Dyslexics	3.96	6.36
CA controls	2.72	4.63
SA controls	4.37	7.76
Old age band		
Dyslexics	2.41	5.15
CA controls	2.06	2.95
SA controls	3.70	5.64

For all nine groups, that is regardless of group or age, the 'X_M' condition was quicker than the 'Y_M' condition. In the case of the young SA controls the confidence level was $p < 0.01$; in all other comparisons between the two conditions it was $p < 0.001$.

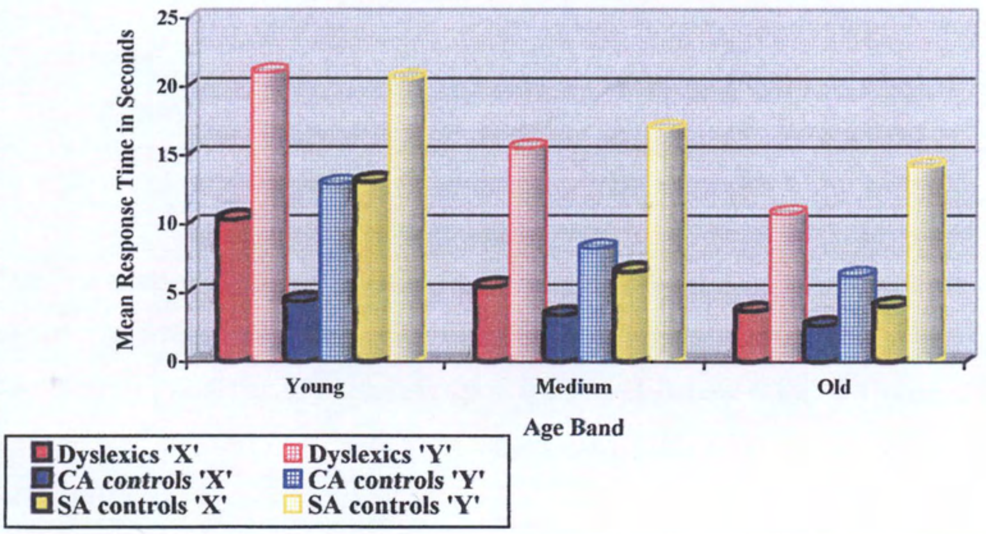
Dyslexics were slower than CA controls but quicker than SA controls. In the 'Y_M' condition the SA controls were quicker than the dyslexics in the young age band ($p < 0.001$)

Table 10.14 Mean response times (seconds) for the three groups and age bands in the 'X_M' condition and 'Y_M' condition for multiplication

Groups and age bands	*'X_M' condition*	*'Y_M' condition*
Young age band		
Dyslexics	10.32	**21.07**
CA controls	4.40	12.90
SA controls	13.08	**20.61**
Medium age band		
Dyslexics	5.46	15.53
CA controls	3.36	8.26
SA controls	6.54	16.95
Old age band		
Dyslexics	3.68	10.73
CA controls	2.62	6.28
SA controls	4.05	14.21

Note. Bold figures indicate the longer mean response time of the young dyslexics compared with the SA controls.

Figure 10.23 Mean response time by group and age band on the 'X_M' and 'Y_M' conditions for multiplication



t-Test results on paired samples 'X_M' versus 'Y_M' for groups and age bands are as follows:

- Young dyslexics $t = 17.254$, $df = 318$, $p < 0.001$
- Young CA controls $t = 13.139$, $df = 318$, $p < 0.001$
- Young SA controls $t = 10.756$, $df = 318$, $p < 0.001$
- Medium-age dyslexics $t = 13.618$, $df = 318$, $p < 0.001$
- Medium-age CA controls $t = 8.448$, $df = 318$, $p < 0.001$
- Medium-age SA controls $t = 14.551$, $df = 318$, $p < 0.001$
- Old dyslexics $t = 9.821$, $df = 318$, $p < 0.001$
- Old CA controls $t = 6.340$, $df = 318$, $p < 0.001$
- Old SA controls $t = 15.216$, $df = 318$, $p < 0.001$

Results of analysis of variance on the two conditions are given in Table 10.15.

Table 10.15 Analysis of variance on the 'XM' and 'YM' conditions

Source	*Dependent variable*	*F value*	*Significance*
Group	'XM'	(2,1431) 99.324	$p < 0.001$
	'YM'	(2,1431) 194.376	$p < 0.001$
	'XM' compared to 'YM'	(2,2862) 292.319	$p < 0.001$
Age	'XM'	(2,1431) 173.957	$p < 0.001$
	'YM'	(2,1431) 159.841	$p < 0.001$
	'XM' compared to 'YM'	(2,2862) 322.353	$p < 0.001$
Group/Age intercept	'XM'	(4,1431) 24.136	$p < 0.001$
	'YM'	(4,1431) 4.577	$p < 0.001$
	'XM' compared to 'YM'	(4,2862) 11.999	$p < 0.001$
Age/Condition intercept	'XM' compared to 'YM'	(2,2862) 7.196	$p < 0.001$
Group/Condition intercept	'XM' compared to 'YM'	(2,2862) 29.991	$p < 0.001$
Age/Group/Condition intercept	'XM' compared to 'YM'	(4,2862) 10.826	$p < 0.001$

Post hoc tests on the 'XM' condition (multiple comparisons using Tamhane) show a significant difference between the dyslexics and the CA controls ($p < 0.001$), between the dyslexics and the SA controls ($p < 0.01$) and between the CA controls and SA controls ($p < 0.001$) as well as a significant difference between the age bands ($p < 0.001$).

Post hoc tests on the 'Y_M' condition (Tamhane) show a significant difference between the dyslexics and the CA controls ($p < 0.001$), between the dyslexics and the SA controls ($p < 0.01$) and between the CA controls and SA controls ($p < 0.001$) as well as a significant difference between the age bands ($p < 0.001$).

Post hoc tests on the 'X_M' compared to the 'Y_M' condition (Tamhane) show a significant difference between the groups ($p < 0.001$) and between the age bands ($p < 0.001$).

10.9 Chapter Summary – Questions Answered

Question 1: *Do dyslexics need more time than non-dyslexics to perform multiplication?*

The answer to this question is 'yes' and 'no' depending upon which group of non-dyslexics the dyslexics are compared with.

A multiplication table is cited as, for example, '7×' with the number of the multiplication table preceding the '×' sign. Where a result was statistically significant a 'p' value has been given.

An analysis of variance on the mean response times showed a significant difference between the groups ($p < 0.001$) and between the age bands ($p < 0.001$), but no significant interaction between age and group. Post hoc tests (Tamhane) showed a significant difference ($p < 0.001$) between the groups except for a non-significant difference between the dyslexics and the SA controls. A significant difference ($p < 0.001$) was found between the young and medium age band, the young and old age band, and the medium-age and old age band ($p < 0.02$). Additionally, t-Tests comparing the groups in each age band showed a significant difference between the groups except for non-significant findings in the young and the medium-age bands between the dyslexics and SA controls. The speed of response was slowest for the young age band, then the medium age band with the old age band responding the quickest. For example, the mean response time for the young CA controls was 7.75 seconds, for the young dyslexics this was 13.02 seconds and for the young SA controls the mean was 15.14 seconds. The SA controls were slower than the other two groups in each age band with the CA controls being the quickest. The standard deviations were similar across group age bands.

The difference between the groups, age bands and the group and age band on each of the 12 times tables (in Table 10.2) were very highly significant ($p < 0.001$) except for a lower level of significance ($p < 0.05$ and $p < 0.01$) on group and age band interaction for the 8× and 9× respectively. Post hoc tests (Tamhane) showed a significant difference ($p < 0.001$) between groups and also age bands for all tables, except on the 7× and 9× ($p < 0.01$) and the 12x ($p < 0.05$) between the dyslexics and SA controls.

There was a significant correlation ($p < 0.01$) between the group age bands on order of difficulty of the multiplication tables (see Table 10.12). The correlation was $p < 0.05$ for the medium-age CA controls compared to the old SA controls. Thus the overall order of difficulty in terms of quickest to slowest response times was found as: 1×, 10×, 2×, 5×, 3×, 4×, 11×, 6×, 7×, 9×, 8× and 12×. Thus tables are judged as 'easier' (quicker response time) if the multiplicand is small and if, as in the case of 5×, 10× and 11×, there is a rule or algorithm readily available.

Young dyslexics compared young CA and SA controls

The dyslexics were quicker than the SA controls and slower than the CA controls on each multiplication table. Figure 10.5 illustrates a greater difference between the young dyslexics and the young CA controls than the young dyslexics and young SA controls.

The difference between the mean response times on each multiplication table for groups and age bands was calculated. The difference between the young dyslexics and young CA controls was least for the 1×, 2×, 5× and 10× whereas for all other tables the dyslexics took longer to respond by from 5.35 to 7.13 seconds.

A comparison of the young dyslexics to the young SA controls showed that the least difference between the groups was on the 7×, 8×, 9× and 12×. The greatest difference between the groups was on the 2× (3.44 seconds) with the dyslexics being the quicker.

Medium-age dyslexics compared to medium-age CA and SA controls

The dyslexics were quicker than the medium-age SA controls and slower than the medium-age CA controls on each multiplication table. Figure 10.6 illustrates the greater difference between the dyslexics and the CA controls than the dyslexics and SA controls.

The difference between the mean reaction times on each table for groups and age bands was calculated: the difference between the dyslexics and the CA controls was least for the 1×, 5×, 10× and 11× whereas the greatest difference was on 7×, 8× and 9×.

A comparison of dyslexics to SA controls showed that the least difference between the groups was on 1×, 10× and 12×. The greatest difference between the groups was on 11× (2.42 seconds).

Old dyslexics compared to old CA and SA controls

The dyslexics were faster than the SA controls and slower than the CA controls on each table. Figure 10.7 illustrates the spread of differences between the groups. The difference between the mean response times on each multiplication table for groups and age bands was calculated: the difference between the dyslexics and CA controls was least for 1×, 2×, 5×, 10× and 11× whereas the greatest difference was on 6× (2.89 seconds).

A comparison of the old dyslexics with the old SA controls showed the least difference between the groups on 1×, 10× and 11×. The greatest difference between the two groups was on 8× (3.38 seconds).

A further way of comparing the group performance was by the use of 'topographical terrain' diagrams, as shown in Figures 10.14 to 10.22. These represent the mean correct response times for the ten members of each group age band on each of the 144 multiplication facts (all combinations of multiplicand and multiplier from 1×1 to 12×12). The main points for the three groups in each age band will be considered in turn:

(1) *Young dyslexics.* Compared to the young CA controls the dyslexics have longer response times represented by higher terrain. There is a 1×/2× and 5× valley and to a greater extent a 10× valley with most of the responses being within the range of 10–20 seconds, spread across the tables (including the 2×, 3× and 4×). Peaks of greater than 20 seconds occur on the 12× and a high plateau exists for the 6×, 7×, 8× and 9× where the multipliers are also 6, 7, 8 and 9. The highest peaks are on 9×12 (21.94 seconds) and 12×11 (21.89 seconds).

(2) *Young SA controls.* This group has a similar terrain to the young dyslexics with a pronounced 10× valley. The highest peaks are 8×8 (22 seconds), 8×12 (21.66 seconds), 9×8 (21.56 seconds), 12×8 (21.51 seconds) and 11×12 (21.48 seconds).

(3) *Young CA controls.* Their terrain is mostly within the 5–10 second range with several results appearing in the 0–5 second range. There are virtually no difficulties with lower numbers and there are no responses that are greater than 20 seconds. The highest peak is on 12×11 and 11×11 (16.77 seconds). There is a marked 10× valley and a slight 5× valley.

Therefore the young dyslexics have a higher terrain in comparison to the young CA controls but are responding like the young SA controls.

(4) *Medium-age dyslexics.* This group make most of their responses within 5–10 seconds. The 1× and 10× valleys lie in the 0–5 second range with the highest peaks found in the 15–20 second range, which are on the 6×, 7×, 8× and 9× where the multipliers are 6, 7, 8 and 9. The greatest peak is on 12×11, which is at a height of 20.12 seconds.

(5) *Medium-age SA controls.* The 1×/2×, 5× and 10×/11× valley is evident. Most responses are between 5 and 15 seconds with a mountainous region for 6×, 7×, 8× and 9× where the multipliers are 6, 7, 8 and 9. The highest peak is on 11 × 12 at 20.1 seconds.

(6) *Medium-age CA controls.* Most responses are made in the range 0–10 seconds with the highest peak on 11 × 11 (16.75 seconds) and 11 × 12 (16.19 seconds).

Thus the terrain heights are varied according to group with the CA controls being closest to sea level followed by the dyslexics and then the SA controls. One uniting factor is that the highest peaks are consistently found on 11 × 12 or 12 × 11 for all.

(7) *Old dyslexics.* Most responses are in the range 0–10 seconds. The 1×/2×, 5× and 10×/11× valleys are present with peaks on the 7×, 8×, 9× and 12× with multipliers 6, 7, 8 and 9. The highest peak is on 11 × 11 (16.57 seconds and 11 × 12 (16.02 seconds).

(8) *Old SA controls.* The range of responses is mainly from 0–15 seconds, which is slightly higher than the old dyslexics. The 1×/2×, 10× and a slight 5× valley are present and there are peaks of 15–20 seconds. The highest peak is 16.21 seconds (11 × 12).

(9) *Old CA controls.* Most responses are from 0 to 5 seconds with only a few isolated number facts causing problems. These are: 7 × 12, 8 × 12, 9 × 7, 11 × 11, 11× 12 (the highest time at 12.57 seconds), 12 × 7, 12 × 8 and 12 × 11. Thus the responses made by the old CA controls are the fastest of all the group age bands.

Thus from the young to the old dyslexics there were persistent problems with any product involving 6, 7, 8, 9 and 12. The young dyslexics showed particular problems with even small numbers except for the 1×, 2×, 5× and 10×.

The SA controls perform worse than the dyslexics. One must assume, however, that with increasing age their performance will come to resemble that of the CA controls. The performance of the medium-age dyslexics and young CA controls is similar, as is that between the old dyslexics and the medium-age CA controls, in terms of response times and terrains.

Thus the dyslexics need more time than the CA controls to answer multiplication questions.

Question 2: *Are younger dyslexics slower than older dyslexics?*

The answer to this question is 'yes'. In general the dyslexics improved in response time with age but the greatest gap was between the young and medium age bands. This was like the performance of the SA controls. In contrast the CA controls improved steadily with age (see Figures 10.8 to 10.10).

Comparing the young dyslexics to the medium-age dyslexics

The medium-age dyslexics were significantly quicker than the young dyslexics ($p < 0.001$). This was also the case for the CA and SA controls ($p < 0.001$). The shape of Figure 10.11 is similar for the dyslexics and CA controls except that the difference between the young dyslexics and medium-age dyslexics is greater than for the CA controls. The difference for the SA controls did not follow the similar pattern found by the dyslexics and CA controls.

Comparing medium-age dyslexics to old dyslexics

The old dyslexics were significantly quicker than the medium-age dyslexics ($p < 0.001$). This was also the case for the CA and SA controls ($p < 0.001$).

It follows from these results that there was a significant difference of $p < 0.001$ between the young and old age bands for each group.

Question 3: *Are there any special number combinations that are more likely than others to take more time?*

The topographical terrain diagrams showed that there was a consistently difficult question for all group age bands: 11×12 or 12×11. The longest mean response time recorded for this question was 21.89 seconds by the young dyslexics compared to 16.77 seconds by the young CA controls.

An 'X_M' and 'Y_M' condition was chosen as for Multiplication Correct (see Chapter 6). A study of median times showed than the 'X_M' condition was answered faster than the 'Y_M' condition ($p < 0.001$) for all group age bands except the young SA controls where the confidence level was $p < 0.01$. The dyslexics were slower than the CA controls but quicker than the SA controls with one exception – the median time for the young SA controls was 8.34 seconds, which meant that they were quicker ($p < 0.001$) than the young dyslexics who had a median time of 14.15 seconds on the 'Y_M' condition.

A study of the mean response time showed that the young SA controls answered the 'Y_M' condition faster than the young dyslexics. A comparison of 'X_M' and 'Y_M' conditions using t-Tests showed that there was a significant difference ($p < 0.001$) for all group age bands. The 'X_M' condition was answered significantly quicker than the 'Y_M' condition. An analysis of variance on the 'X_M' and 'Y_M' conditions showed that there was a significant difference between the groups, age bands and intercept of group and age ($p < 0.001$) on the 'X_M' condition, on the 'Y_M' condition and on the 'X_M' compared to the 'Y_M' condition. Post hoc tests (Tamhane) on the 'X_M' condition showed significant differences between the dyslexics and CA controls ($p < 0.001$), the dyslexics and SA controls ($p < 0.01$) and between the CA and SA controls ($p < 0.001$), as well as between each of the age bands ($p < 0.001$). On the 'Y_M' condition the same results were also found with the same confidence levels. Post hoc tests (Tamhane) on 'X_M' compared to 'Y_M' showed a significant difference ($p < 0.001$) between the groups and between the age bands.

Thus the dyslexics were significantly slower than the CA controls on the easier 'X_M' condition as well as on the 'Y_M' condition. The median results showed that unusually the young SA controls performed better than the young dyslexics on the harder condition ('Y_M'). Thus when questions are hard for non-dyslexics they are particularly hard for dyslexics – especially in the young age band.

CHAPTER 11

Speed of Division

11.1 Aims of This Chapter
11.2 Overall Comparisons
11.3 Tasks Within Division
11.4 Differences Between the Dyslexics and Non-dyslexics on Division Tables
11.5 Comparing Age Bands Within the Separate Groups
11.6 Order of Difficulty
11.7 Topographical Terrains for Division
11.8 Special Number Combinations in Division
11.9 Chapter Summary – Questions Answered

11.1 Aims of This Chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of division:

(1) Do dyslexics need more time than non-dyslexics?
(2) Are younger dyslexics slower than older dyslexics?
(3) Are there any special number combinations that are more likely than others to take more time?

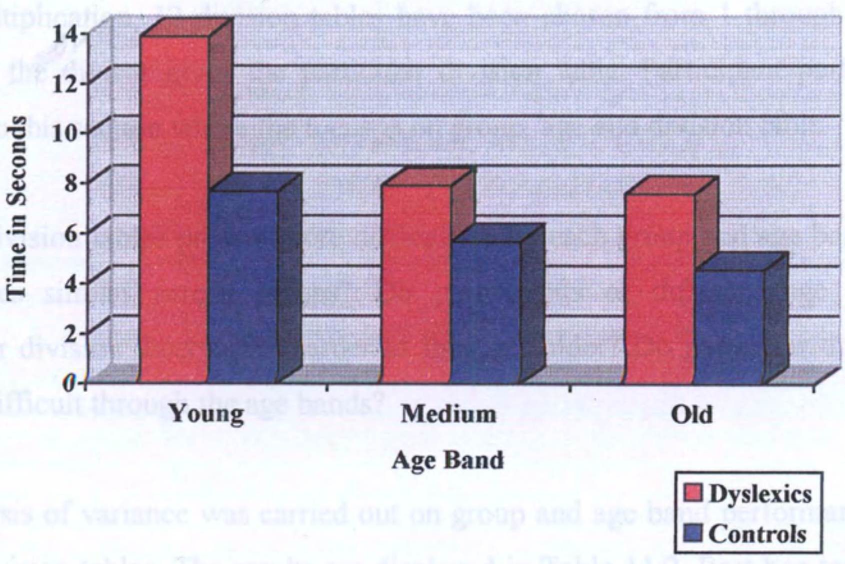
11.2 Overall Comparisons

The mean, standard deviation and median response times (in seconds) are given for groups and age bands in Table 11.1. The mean response time is illustrated in Figure 11.1.

Table 11.1 Mean and median response times (in seconds) and standard deviation by group and age on division

Groups	*Age bands*	*Mean*	*Standard deviation*	*Median*
Dyslexics	Young	13.90	3.65	13.10
	Medium	7.91	2.51	8.41
	Old	7.58	2.76	7.15
Controls	Young	7.69	2.08	8.01
	Medium	5.67	2.06	5.35
	Old	4.55	0.94	4.79

Figure 11.1 Mean response time by group and age on division



Analysis of variance shows the following overall results:

There is a significant main effect between groups (F (1,54) = 35.913, p < 0.001).
There is a significant main effect between age bands (F (2,54) = 21.196, p < 0.001).
There is a significant interaction between group and age (F (2,54) = 3.604, p < 0.05).

Analysis of variance tables are presented in Appendix F6.

Post hoc tests using Tamhane (multiple comparisons) show that there is a significant difference between the young and medium age band ($p < 0.01$) and the young and old age band ($p < 0.01$) but not between the medium and the old age band (ns).

A comparison of the dyslexics and non-dyslexics in each age band using t-Tests show:

- Young ($t = 4.673$, $df = 18$, $p < 0.001$)
- Medium-age ($t = 2.180$, $df = 18$, $p < 0.05$)
- Old ($t = 3.289$, $df = 18$, $p < 0.01$)

11.3 Tasks Within Division

Division can be broken down into various tasks. So as to align the study of division with multiplication, 12 division tables have been chosen from 1 through to 12. The value of the divisor gives the particular division table. Participant performance is studied in this section where the focus is on group, age and division table.

Which division tables present more difficulties for each group and age band? Are the difficulties similar across groups? Do participants of different age bands find particular division facts easier/harder as they get older? Do particular division facts remain difficult through the age bands?

An analysis of variance was carried out on group and age band performance on each of the division tables. The results are displayed in Table 11.2. Post hoc tests between groups and age bands are given in Tables 11.3 and 11.4 respectively.

Table 11.2 Analysis of variance results (between-subjects effects) showing significant differences in mean response times between groups, age bands and the intercept of groups and age bands

Division table	*Groups*	*Age bands*	*Group and age band*
1	7.868**	6.932**	2.360
2	26.144***	20.071***	4.289*
3	20.750***	24.515***	2.349
4	15.607***	19.525***	2.936
5	18.079***	12.964***	2.746
6	32.533***	11.311***	1.971
7	28.119***	13.862***	1.215
8	23.968***	14.511***	2.142
9	25.753***	11.867***	2.107
10	13.062***	11.610***	3.912
11	16.420***	8.549***	3.268*
12	45.867***	10.980***	1.216
	$F(1, 54)$	$F(2,54)$	$F(2,54)$

Significance levels key for Tables 11.2, 11.3 and 11.4:

*** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

Table 11.3 Post hoc tests (t-Test) between groups

Division table	*Group comparisons in each age band*		
	Young	*Medium-age*	*Old*
1	2.073	0.172	3.075**
2	4.044***	1.789	2.780*
3	3.650**	1.640	2.418*
4	3.608**	1.515	1.367
5	3.218**	1.696	2.242*
6	4.911***	2.330*	2.641*
7	5.296***	1.958	2.586*
8	5.199***	1.253	2.646*
9	5.439***	1.282	2.911**
10	2.768*	1.560	3.089**
11	2.955**	1.703	2.637*
12	4.347***	3.784***	3.631**

df = 18

Table 11.4 Post hoc tests (multiple comparisons – Tamhane) between age bands

Division table	*Age band comparisons*		
	Y/M	*Y/O*	*M/O*
1	ns	*	ns
2	**	***	ns
3	***	***	ns
4	***	***	ns
5	*	**	ns
6	*	*	ns
7	*	***	ns
8	**	***	ns
9	*	***	ns
10	*	**	ns
11	ns	*	ns
12	*	*	ns

Key: Y (young age band), M (medium age band), O (old age band).

The mean response times for the groups in each age band are presented in Tables 11.5, 11.6, and 11.7 and illustrated in Figures 11.2, 11.3 and 11.4.

Table 11.5 Mean response time (in seconds) for each division table by group in the young age band (standard deviation in brackets)

Division table	*Dyslexics*	*Controls*
1	7.52 (4.88)	4.17 (1.52)
2	10.83 (3.30)	5.23 (2.87)
3	13.67 (4.09)	8.21 (2.37)
4	15.60 (4.14)	9.53 (3.34)
5	12.22 (5.06)	6.38 (2.72)
6	16.00 (3.61)	8.57 (3.15)
7	16.65 (3.00)	9.53 (3.01)
8	17.35 (2.94)	10.65 (2.81)
9	16.82 (3.62)	9.14 (2.60)
10	10.32 (6.42)	4.54 (1.54)
11	12.04 (5.55)	6.40 (2.37)
12	17.85 (3.96)	9.95 (4.17)

Figure 11.2 Mean response time for each division table by group and young age band

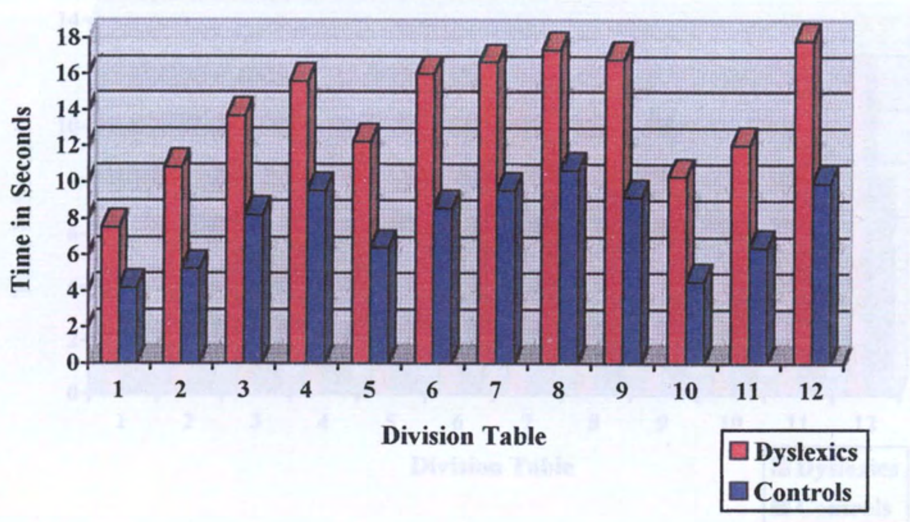


Table 11.6 Mean response time (in seconds) for each division table by group in the medium age band (standard deviation in brackets)

Division table	*Dyslexics*	*Controls*
1	3.60 (1.43)	3.49 (1.50)
2	5.41 (1.94)	3.77 (2.16)
3	6.91 (2.88)	4.95 (2.43)
4	8.55 (2.77)	6.50 (3.26)
5	6.36 (2.52)	4.62 (2.07)
6	9.66 (4.06)	6.14 (2.52)
7	10.44 (4.97)	6.79 (3.18)
8	10.26 (3.54)	8.14 (3.99)
9	10.05 (4.57)	7.44 (4.51)
10	4.71 (2.46)	3.36 (1.22)
11	6.96 (1.60)	5.48 (2.24)
12	12.07 (3.31)	7.41 (2.06)

Figure 11.3 Mean response time for each division table by group and medium age band

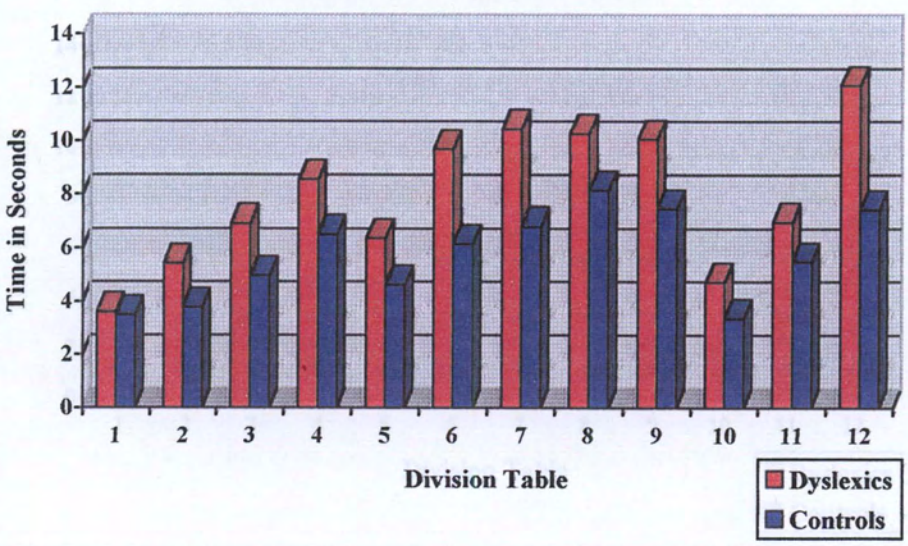
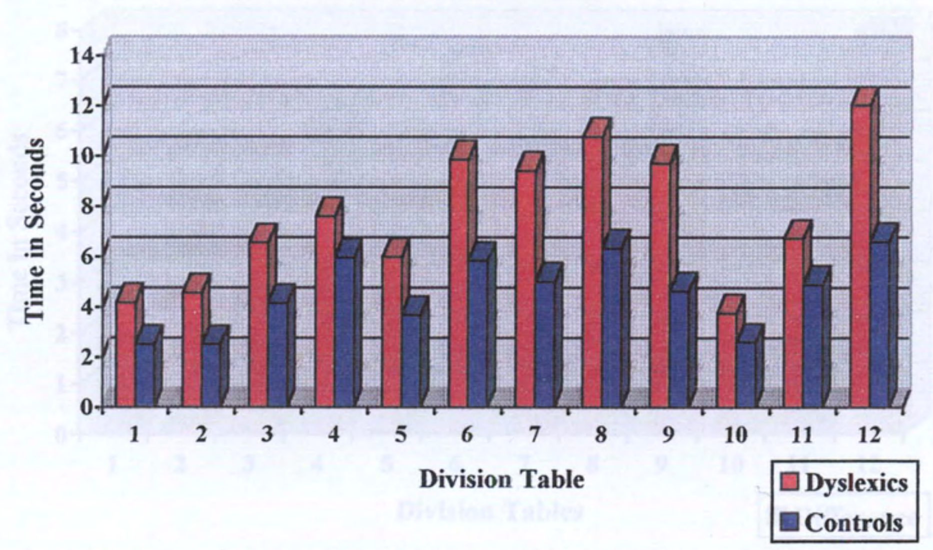


Table 11.7 Mean response time (in seconds) for each division table by group in the old age band (standard deviation in brackets)

Division table	*Dyslexics*	*Controls*
1	4.17 (1.42)	2.51 (0.95)
2	4.56 (2.13)	2.50 (0.98)
3	6.54 (2.80)	4.14 (1.42)
4	7.59 (2.95)	5.95 (2.40)
5	5.97 (2.97)	3.67 (1.27)
6	9.85 (4.43)	5.82 (1.91)
7	9.40 (5.26)	5.00 (1.15)
8	10.77 (4.70)	6.32 (2.51)
9	9.70 (5.20)	4.62 (1.82)
10	3.74 (0.81)	2.59 (0.85)
11	6.71 (1.60)	4.88 (1.50)
12	12.01 (4.39)	6.58 (1.77)

Figure 11.4 Mean response time for each division table by group and old age band



11.4 Differences Between the Dyslexics and Non-dyslexics on Division Tables

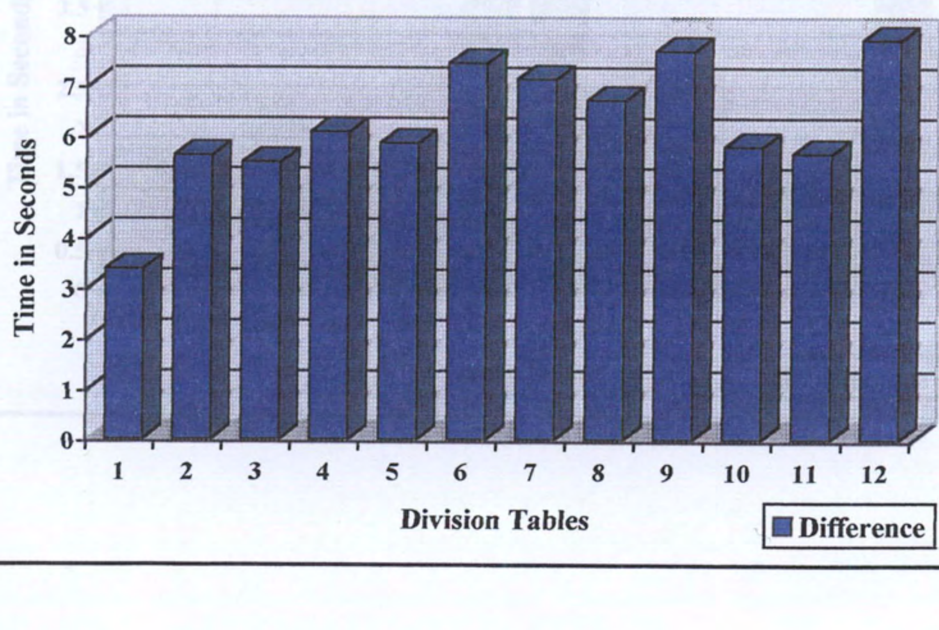
The information in this section does not display new data but draws on the results found in section 11.3. This section enables the reader to analyse the differences found in the mean times between the two experimental groups.

Firstly, a study was made of the difference between the groups in the young age band. See Table 11.5 for the main results from which the 'Difference' in Table 11.8 was drawn. The results are illustrated in Figure 11.5.

Table 11.8 Differences in mean response times (in seconds) between the dyslexics and the controls in the young age band

	Division table											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Control difference	3.35	5.6	5.46	6.07	5.84	7.43	7.12	6.7	7.68	5.78	5.64	7.90

Figure 11.5 Differences in mean response times between the groups in the young age band



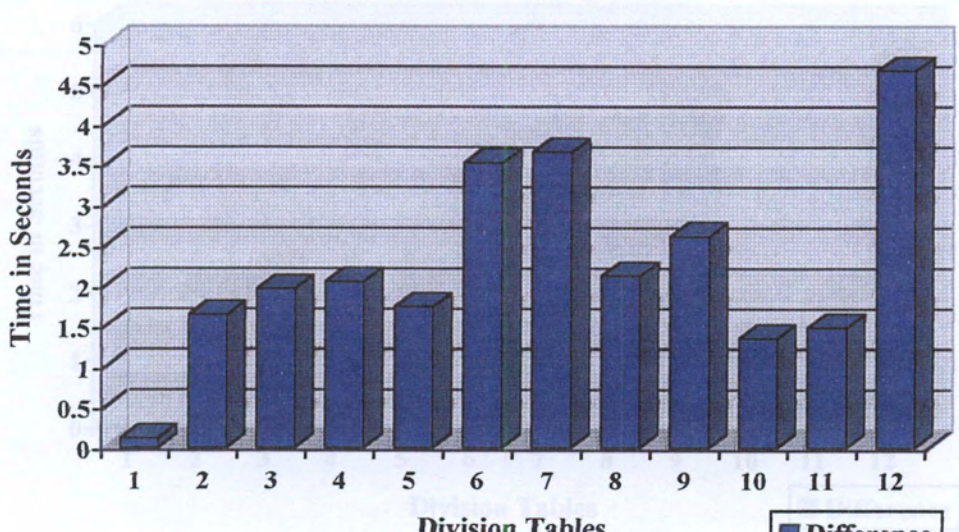
Where the difference is a positive value, the control group performed quicker than the dyslexic group.

Secondly, a study was made of the difference between the groups in the medium age band. See Table 11.6 for the main results from which the 'Difference' in Table 11.9 was drawn. The results are illustrated in Figure 11.6.

Table 11.9 Differences in mean response times (in seconds) between the dyslexics and controls in the medium age band

	Division table											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Control difference	0.11	1.64	1.96	2.05	1.74	3.52	3.65	2.12	2.61	1.35	1.48	4.66

Figure 11.6 Differences in mean response times between the groups in the medium age band



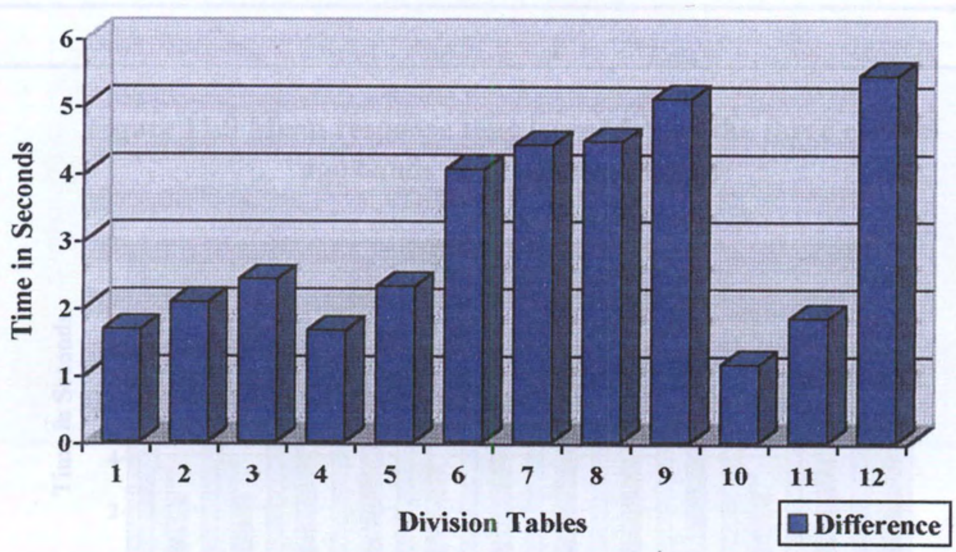
Where the difference is a positive value, the control group performed quicker than the dyslexic group.

Thirdly, a study was made of the difference between the groups in the old age band. See Table 11.7 for the main results from which the 'Difference' in Table 11.10 was drawn. The results are illustrated in Figure 11.7.

Table 11.10 Differences in mean response times (in seconds) between the dyslexics and controls in the old age band

	Division table											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Control difference	1.66	2.06	2.40	1.64	2.30	4.03	4.40	4.45	5.08	1.15	1.83	5.43

Figure 11.7 Differences in mean response times between the groups in the old age band



11.5 Comparing Age Bands Within the Separate Groups

The information in this section does not display new data but draws on the results found in section 11.3. This section enables the reader to compare age band performance within the separate groups. This is illustrated in Figures 11.8 and 11.9.

Figure 11.8 Mean response time (seconds) for the three dyslexic age bands on all division tables

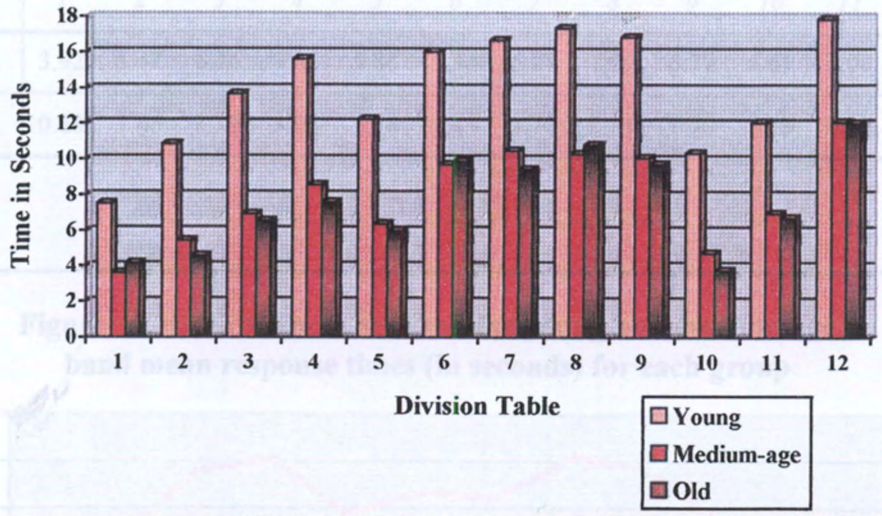
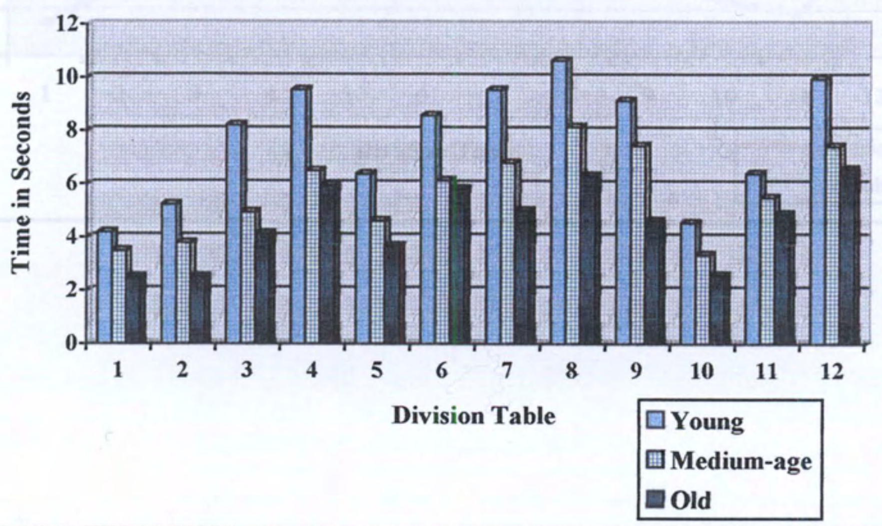


Figure 11.9 Mean response time (seconds) for the three control age bands on all division tables



11.5.1 Comparison of the Young and Medium Age Bands on Division Tasks

This is represented in Table 11.11 and Figure 11.10. Results from post hoc tests are given in Table 11.12.

Table 11.11 Differences between the young and medium age band mean response times (in seconds) for each group

Groups	*Division table*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Dyslexics	3.92	5.42	6.76	7.05	5.86	6.34	6.21	7.09	6.77	5.61	5.08	5.78
Controls	0.68	1.46	3.26	3.03	1.76	2.43	2.74	2.51	1.70	1.18	0.92	2.54

Figure 11.10 Differences between the young and medium age band mean response times (in seconds) for each group

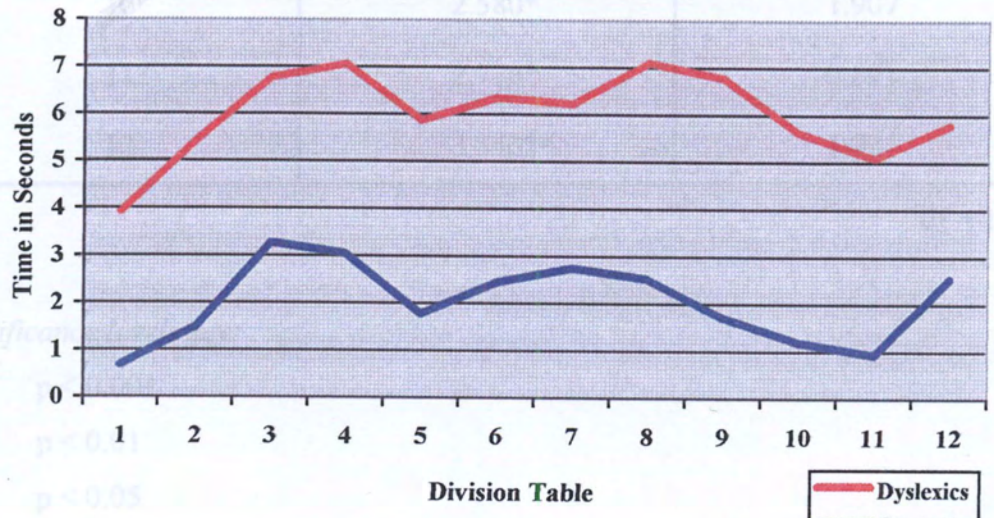


Table 11.12 Post hoc tests (t-Test) between young and medium age bands within groups

Division table	*Group*	
	Dyslexics	*Controls*
1	2.434*	1.007
2	4.473***	1.282
3	4.279***	3.038**
4	4.477***	2.052
5	3.278**	1.631
6	3.696**	1.903
7	3.380**	1.985
8	4.874***	1.627
9	3.670**	1.031
10	2.580*	1.907
11	2.778*	0.891
12	3.546**	1.731

df = 18

Significance levels key:

*** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

11.5.2 Comparison of the Medium and Old Age Bands on Division Tasks

This is represented in Table 11.13 and Figure 11.11. Results from post hoc tests are given in Table 11.14.

Table 11.13 Differences between the medium and old age band mean response times (in seconds) for each group

Group	*Division table*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Dyslexics	–0.57	0.85	0.37	0.96	0.39	–0.19	1.04	–0.51	0.35	0.97	0.25	0.06
Controls	0.98	1.27	0.81	0.55	0.95	0.32	1.79	1.82	2.82	0.77	0.6	0.83

Note. A negative difference ('–') indicates that the medium-age dyslexics had a quicker mean response time than the old dyslexics.

Figure 11.11 Differences between the medium and old age band mean response times (in seconds) for each group

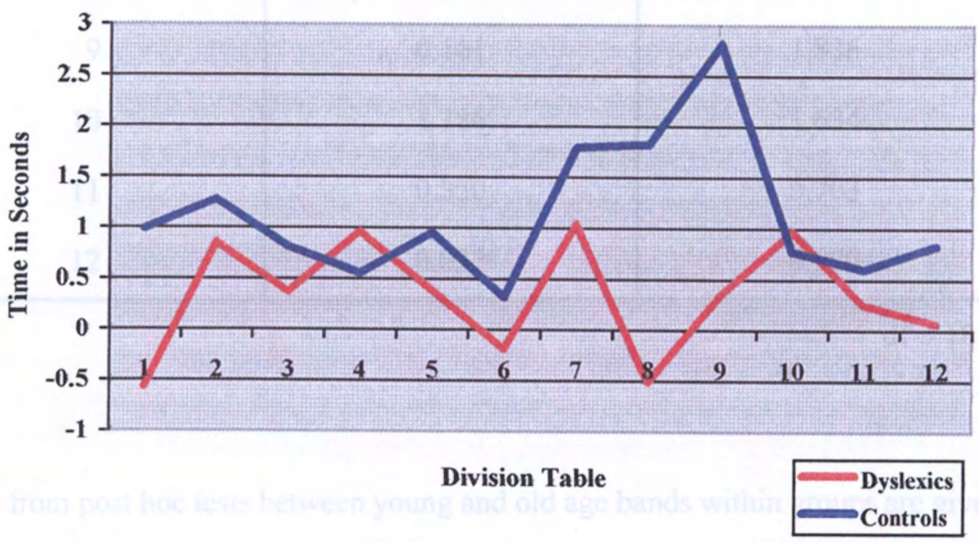


Table 11.14 Post hoc tests (t-Test) between medium and old age bands within groups

Division table	*Group*	
	Dyslexics	*Controls*
1	0.898	1.734
2	0.939	1.698
3	0.286	0.916
4	0.753	0.436
5	0.324	1.232
6	0.101	0.322
7	0.454	1.674
8	0.278	1.226
9	0.161	1.836
10	1.186	1.634
11	0.350	0.703
12	0.032	0.970

df = 18

Results from post hoc tests between young and old age bands within groups are given in Table 11.15.

Table 11.15 Post hoc tests (t-Test) between young and old age bands within groups

Division table	*Group*	
	Dyslexics	*Controls*
1	2.080	2.923**
2	5.045***	2.845*
3	4.548***	4.661***
4	4.985***	2.758*
5	3.371**	2.854*
6	3.403**	2.360*
7	3.784***	4.452***
8	3.748***	3.642**
9	3.550**	4.499***
10	3.215**	3.506**
11	2.915**	1.712
12	3.124**	2.358*

df = 18

Significance levels key:

*** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

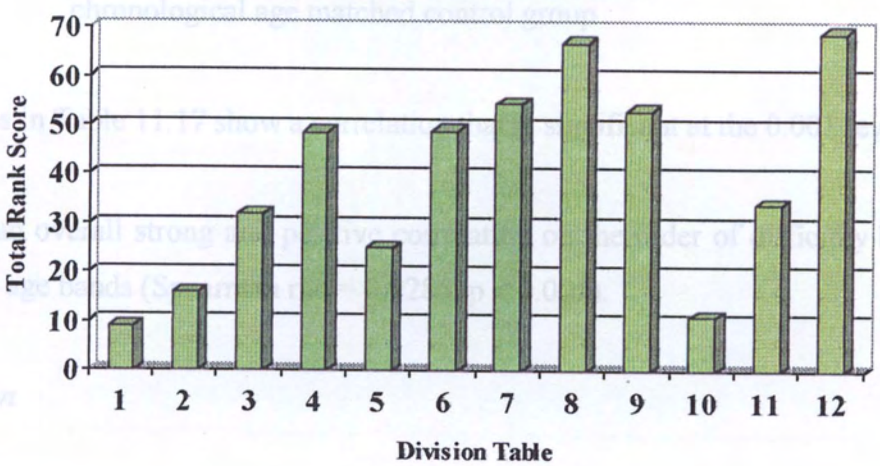
11.6 Order of Difficulty

The results displayed in Tables 11.5, 11.6 and 11.7 show the mean response times for groups and age bands on each division table. Table 11.16 shows the rank order of difficulty of the division tables for each group and age band (Y = young, M = medium-age, O = old) found from these tables. The ranks have been totalled (total rank score) and the 'overall rank' found from these. The results are illustrated in Figure 11.12.

Table 11.16 Order of difficulty for the 12 division tables

Division table	*Dyslexics*			*Controls*			*Total rank score*	*Overall rank*
	Age band							
	Y	*M*	*O*	*Y*	*M*	*O*		
1	1	1	2	1	2	2	9	1
2	3	3	3	3	3	1	16	3
3	6	5	5	6	5	5	32	5
4	7	7	7	9.5	8	10	48.5	7
5	5	4	4	4	4	4	25	4
6	8	8	10	7	7	9	49	8
7	9	11	8	9.5	9	8	54.5	10
8	11	10	11	12	12	11	67	11
9	10	9	9	8	11	6	53	9
10	2	2	1	2	1	3	11	2
11	4	6	6	5	6	7	34	6
12	12	12	12	11	10	12	69	12

Figure 11.12 Division table total rank scores on speed for all groups and age bands combined



The results of non-parametric correlations on the order of difficulty by group and age band are given in Table 11.17.

Table 11.17 Non-parametric correlations using Spearman's rho on order of difficulty in division

	MD	*OD*	*YC*	*MC*	*OC*	*Overall rank*
YD	0.9580	0.9510	0.9457	0.9441	0.8462	0.9720
MD		0.9441	0.9387	0.9301	0.8741	0.9930
OD			0.9142	0.9301	0.9021	0.9650
YC				0.9422	0.9177	0.9562
MC					0.8322	0.9510
OC						0.8951

Key:

Y = young age band
M = medium age band
O = old age band
D = dyslexic group
C = chronological age matched control group

All entries in Table 11.17 show a correlation that is significant at the 0.001 level.

There is an overall strong and positive correlation on the order of difficulty between the group age bands (Spearman rho = 0.9286, $p < 0.001$).

Discussion

If the criterion is speed of performing division, the order of difficulty for the division tables is: ÷1, ÷10, ÷2, ÷5, ÷3, ÷11, ÷4, ÷6, ÷9, ÷7, ÷8 and ÷12.

For division, tables are easier:

(1) if the divisor is small; and

(2) if, as in the case of ÷5, ÷10 and ÷11, there is a rule or algorithm readily available.

11.7 Topographical Terrains for Division

Topographical terrain presentation is a visual way of showing the level of ease or difficulty encountered when group and age band participants tackle particular division tables. The six terrains given in Figures 11.13 to 11.18 have been colour coded according to mean correct response time in seconds. The terrain is designed to reflect the 12 × 12 division grid presented in a three-dimensional form. The dimensions represented are the divisor (division table number), quotient and mean response time (in seconds). The higher the terrain, the longer the response time and ultimately the harder the division question.

Figure 11.13 Mean response time for the young dyslexics

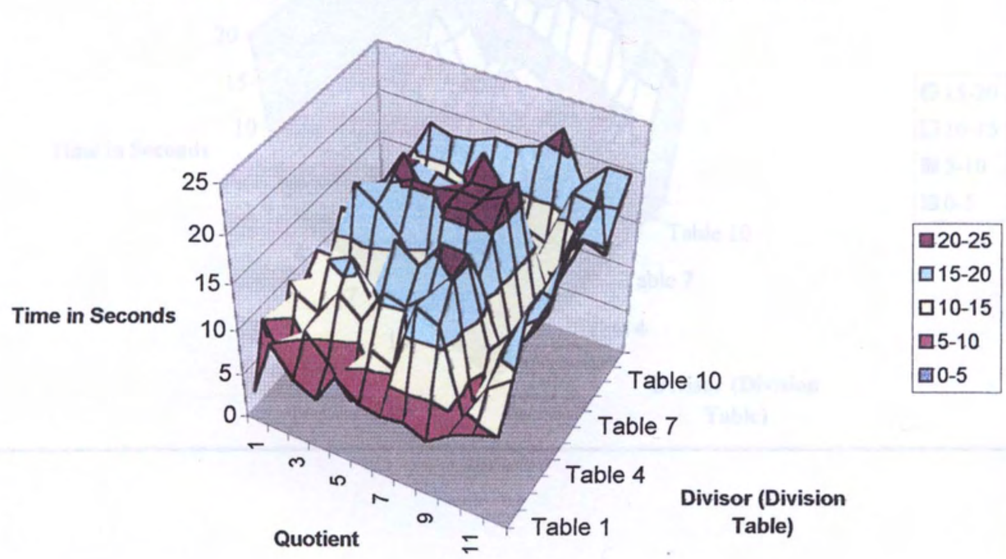


Figure 11.14 Mean response time for the medium-age dyslexics

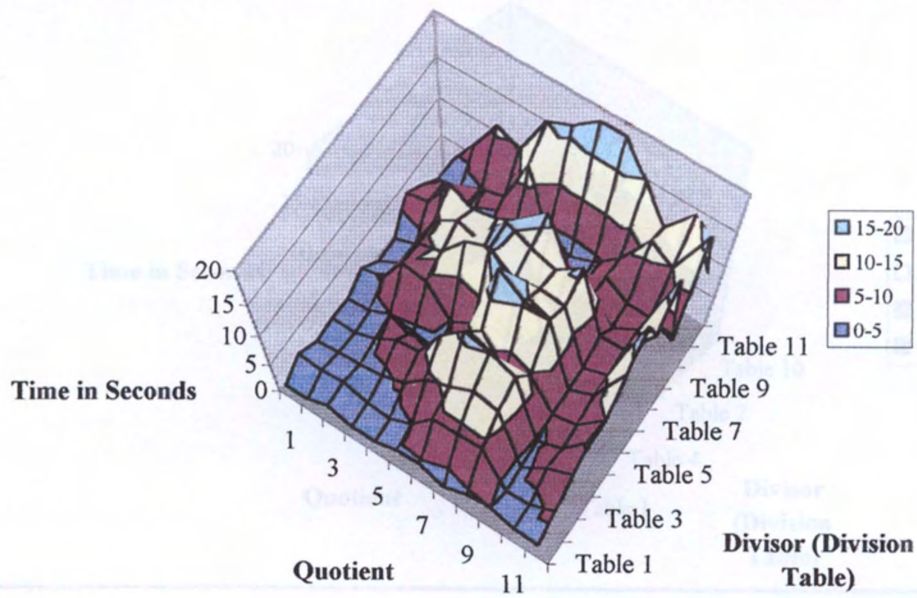


Figure 11.15 Mean response time for the old dyslexics

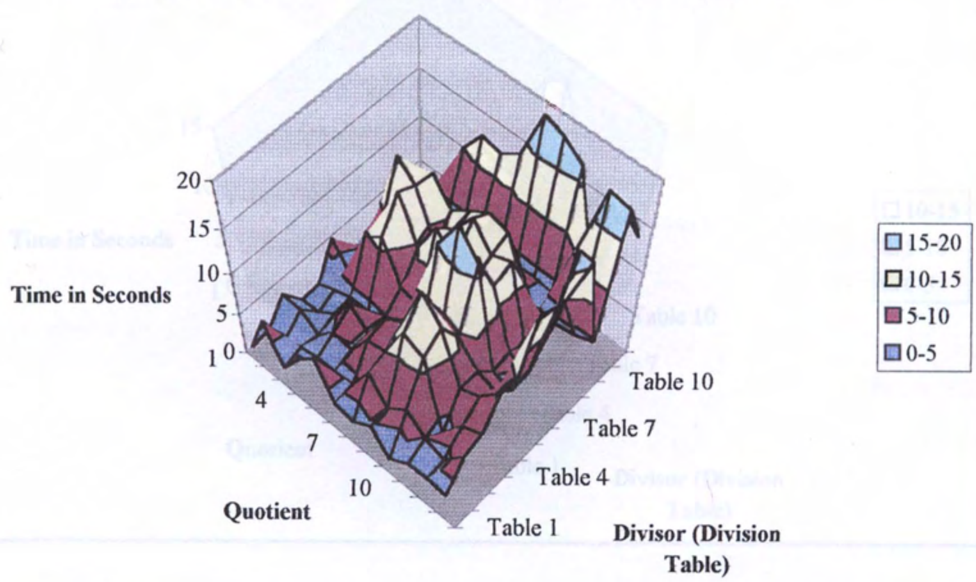


Figure 11.16 Mean response time for the young controls

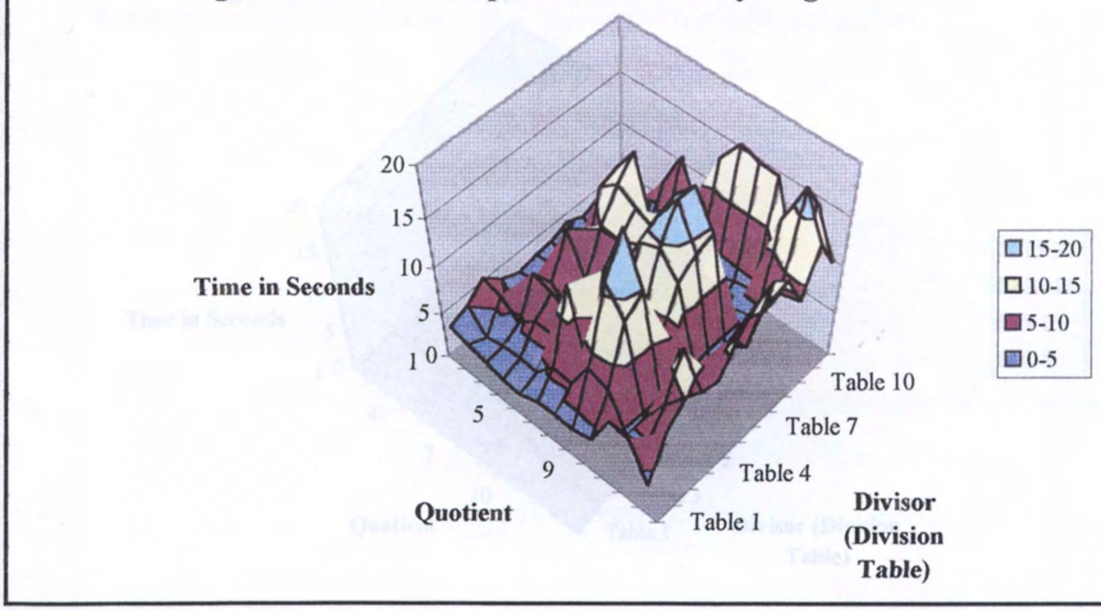


Figure 11.17 Mean response time for the medium-age controls

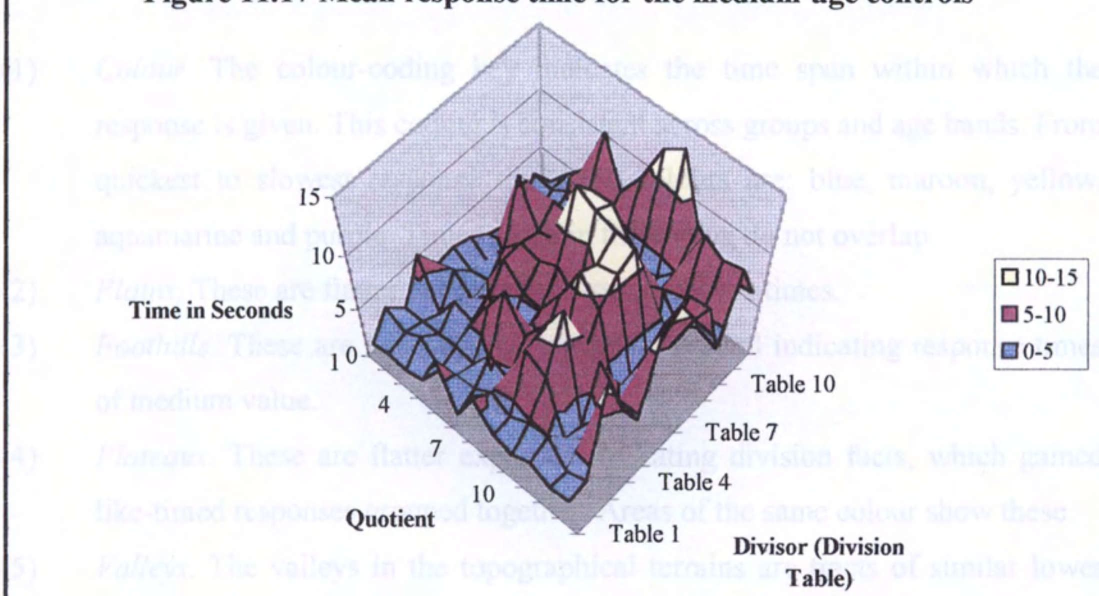
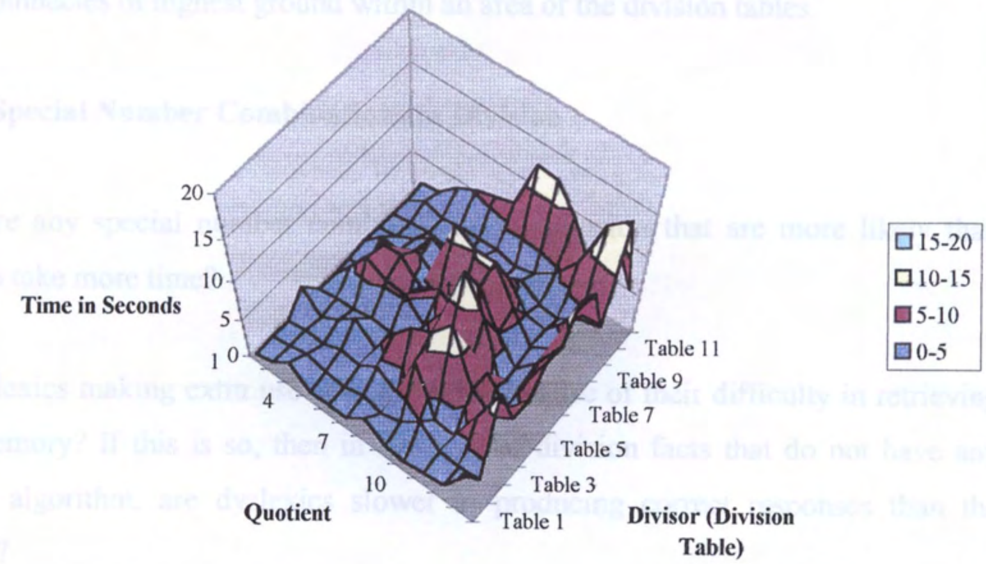


Figure 11.18 Mean response time for the old controls



The terrains have the following properties:

(1) *Colour*. The colour-coding key indicates the time span within which the response is given. This coding is consistent across groups and age bands. From quickest to slowest response times the colours are: blue, maroon, yellow, aquamarine and purple. Times given in the coding do not overlap.

(2) *Plains*. These are flatter expanses of faster response times.

(3) *Foothills*. These are areas of low to middle ground indicating response times of medium value.

(4) *Plateaux*. These are flatter expanses indicating division facts, which gained like-timed responses grouped together. Areas of the same colour show these.

(5) *Valleys*. The valleys in the topographical terrains are tracts of similar lower altitude that run like a track of the same colour through the hills and mountains. These would indicate particular division tables that evoke similar response times throughout the majority of the division table, such as the ÷10 table. The valley stands out because it is bordered by higher land on either side. Here the adjoining division tables would take the participants longer to answer.

(6) *Mountain peaks*. Peaks indicate a sudden climb of difficulty shown by sharp pinnacles of highest ground within an area of the division tables.

11.8 Special Number Combinations in Division

Are there any special number combinations for division that are more likely than others to take more time?

Are dyslexics making extra use of algorithms because of their difficulty in retrieving from memory? If this is so, then in the case of division facts that do not have any obvious algorithm, are dyslexics slower at producing correct responses than the controls?

Sixteen division sums were chosen to test this prediction: 8 of these were selected because they had well known algorithms ('X-type' questions) and 8 other division sums were included because they did not have an obvious algorithm ('Y-type' questions).

Selection of questions was based on the following:

(1) no divisor or quotient less than 6 on the basis of the question being too easy;
(2) no dividend being over 100 on the basis of the question being too hard.

'X-type' questions included sums from the ÷10 and ÷11 tables, which have well known patterns serving as algorithms.

'Y-type' questions were chosen from the ÷7 and ÷8 tables since they have no clear algorithms for the participants to employ.

The division sums that were selected therefore included 7, 8, 10 and 11 as the divisor and 6, 7, 8 and 9 as the quotient.

The 'X-type' sums were: $60 \div 10, 70 \div 10, 80 \div 10, 90 \div 10$

$66 \div 11, 77 \div 11, 88 \div 11, 99 \div 11$

The 'Y-type' sums were: $42 \div 7, 49 \div 7, 56 \div 7, 63 \div 7$

$48 \div 8, 56 \div 8, 64 \div 8, 72 \div 8$

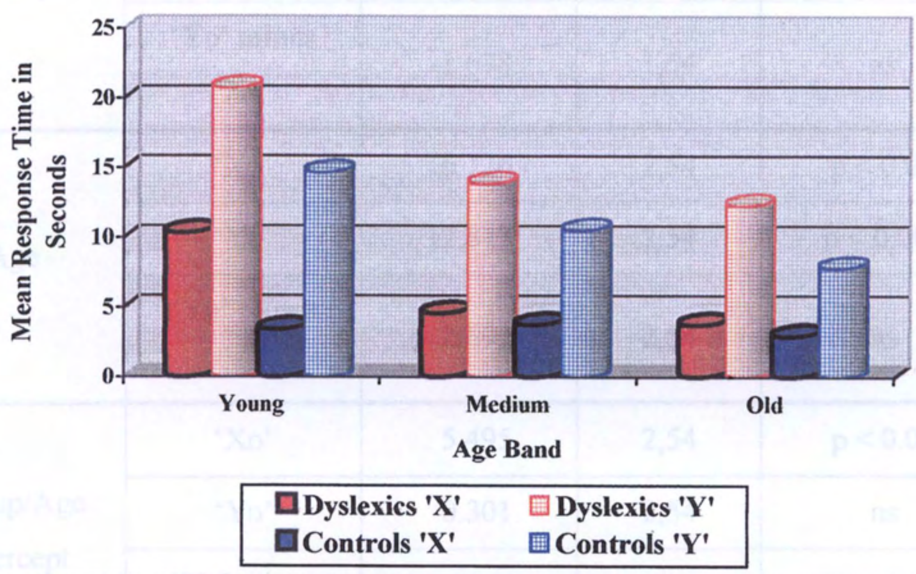
Each division sum was presented once to each participant and thus there were results for 8 'X-type' and 8 'Y-type' division sums. Table 11.18 shows the mean response times made by each group/age band on the 'XD' and 'YD' type condition. The results are illustrated in Figure 11.19.

A 'D' placed after 'X' and 'Y' denotes division.

Table 11.18 Mean response times (seconds) for the three groups and age-bands in the 'XD' condition and 'YD' condition for division

Groups and age bands	*'XD' condition*	*'YD' condition*
Young age band		
Dyslexics	10.32	20.73
Controls	3.42	14.68
Medium age band		
Dyslexics	4.56	14.19
Controls	3.75	10.51
Old age band		
Dyslexics	3.73	12.30
Controls	2.92	7.81

Figure 11.19 Mean response time by group and age band on the 'XD' and 'YD' conditions for division



t-Test results on paired samples 'XD' versus 'YD' for groups and age bands are as follows:

- Young controls $t = 7.855$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 4.607$, $df = 9$, $p < 0.001$
- Medium-age controls $t = 3.791$, $df = 9$, $p < 0.01$
- Medium-age dyslexics $t = 6.185$, $df = 9$, $p < 0.001$
- Old controls $t = 3.711$, $df = 9$, $p < 0.01$
- Old dyslexics $t = 3.910$, $df = 9$, $p < 0.01$

Results of analysis of variance on the two conditions are given in Table 11.19.

Table 11.19 Analysis of variance on the 'XD' and 'YD' conditions

Source	*Dependent variable*	*F value*	*df*	*Significance*
Group	'XD'	10.784	1,54	$p < 0.01$
	'YD'	13.990	1,54	$p < 0.001$
	'YD' minus 'XD'	1.678	1,54	ns
Age	'XD'	6.126	2,54	$p < 0.01$
	'YD'	12.813	2,54	$p < 0.001$
	'YD' minus 'XD'	2.695	2,54	ns
Group/Age intercept	'XD'	5.495	2,54	$p < 0.01$
	'YD'	0.301	2,54	ns
	'YD' minus 'XD'	0.906	2,54	ns

Multiple comparison post hoc tests using Tamhane on groups combined showed:

- No significant difference between each of the age bands in the 'XD' condition.
- On the 'YD' condition a comparison between the young and the medium age bands showed significance ($p < 0.01$) as well as between the young and old age bands ($p < 0.001$) but not between the medium and old age band (ns).
- No significant difference was found between each of the age bands in the 'YD' minus 'XD' condition.

t-Test results on dyslexics versus controls on the 'XD' and 'YD' conditions in each age band are as follows:

Young:

- 'XD' condition $t = 2.925$, $df = 18$, $p < 0.01$
- 'YD' condition $t = 4.088$, $df = 18$, $p < 0.001$
- 'YD' minus 'XD' $t = 0.318$, $df = 18$, ns

Medium-age:

- 'XD' condition $t = 0.892$, $df = 18$, ns
- 'YD' condition $t = 1.442$, $df = 18$, ns
- 'YD' minus 'XD' $t = 1.211$, $df = 18$, ns

Old:

- 'XD' condition $t = 1.378$, $df = 18$, ns
- 'YD' condition $t = 1.872$, $df = 18$, ns
- 'YD' minus 'XD' $t = 1.438$, $df = 18$, ns

11.9 Chapter Summary – Questions Answered

Question 1: *Do dyslexics need more time than non-dyslexics to perform division?*

The answer to this question is 'yes'.

A '÷' sign placed before a number indicates a particular division table. An analysis of variance on the mean response times showed that the controls were significantly faster than the dyslexics ($p < 0.001$) and that there was a significant difference between age bands ($p < 0.001$), where the younger the age band the slower the response. There was also a significant interaction between group and age ($p < 0.05$). Post hoc tests (Tamhane) showed that the medium age band was faster than the young age band ($p < 0.01$) but no significant difference in response time was found between the medium and old age bands. The dyslexics were significantly slower than the controls in the young ($p < 0.001$), medium-age ($p < 0.05$) and old ($p < 0.01$) age bands on t-Tests.

A correlation analysis (in section 11.6) showed that there was an overall strong and positive correlation between the group age bands on the order of difficulty of the twelve division tables (Spearman rho = 0.9286, $p < 0.001$). The order of difficulty from the quickest to the slowest table was: ÷1, ÷10, ÷2, ÷5, ÷3, ÷11, ÷4, ÷6, ÷9, ÷7, ÷8 and ÷12.

An analysis of variance on the response times by participants for each of the division tables (in Table 11.2) showed that the controls were significantly faster than the dyslexics on all tables at $p < 0.001$ and $p < 0.01$ on the ÷1. There was a significant difference between the age bands on all division tables ($p < 0.001$, except ÷1 at a 'p' value of 0.01). Only on ÷2 and ÷11 was there a significant interaction between group and age band ($p < 0.05$). Post hoc tests showed (in Table 11.4) no significant difference between the medium and old age bands but significant differences between the young and medium age bands for all tables except ÷1 and ÷11.

Comparing young dyslexics with young controls

Post hoc tests (t-Tests) between groups (presented in Table 11.3) showed that the young dyslexics were significantly slower than the young controls on all tables except ÷1. The results on ÷2, ÷6, ÷7, ÷8, ÷9 and ÷12 were very highly significant ($p < 0.001$) whereas the ÷3, ÷4, ÷5 and ÷11 were at $p < 0.01$ and the ÷10 was found to be at the significance level of $p < 0.05$. The mean response time for the young dyslexics on the ÷2 was 10.83 seconds whereas it was 5.23 seconds for the young controls. Where a division table took longer for the young controls, it took extra long for the young dyslexics (see Table 11.5 and Figure 11.2). The greatest difference in mean response times between the groups was on the 'harder' division tables, for example, ÷6, ÷7, ÷8, ÷9 and ÷12.

Comparisons between the topographical terrain diagrams for the two groups (Figures 11.13 and 11.16) show the following. The young dyslexics have a higher terrain (mean response time) with a raised plateau for the ÷6, ÷7, ÷8 and ÷9 where the quotient is 6, 7, 8 and 9. Difficulties occur even in the lower division tables and quotients. The ÷1 and ÷10 valley is clearly demarcated.

The young controls have quicker response times and therefore a lower terrain where several questions were answered in a mean response time of 0–5 seconds. The ÷1/÷2 and ÷10/÷11 response times produce wider valleys than the young dyslexic terrain. A small ÷5 valley is visible. There is no plateau as for the young dyslexics, but more pronounced peaks, for example on 32 ÷ 4, 56 ÷ 8, 64 ÷ 8 and 121 ÷ 11.

Comparing the medium-age dyslexics to the medium-age controls

The medium-age dyslexics had significantly comparable mean response times to the medium-age controls on all tables except ÷6 ($p < 0.05$) and ÷12 ($p < 0.001$) where the controls were quicker. On ÷12 the medium-age dyslexics took a mean time of 12.07 seconds to answer, compared to the mean time of 7.41 seconds for the medium-age controls (see Table 11.6). The smallest difference between the groups was on the ÷1 (0.11 seconds).

Comparisons between the topographical terrain diagrams for the two groups (Figures 11.14 and 11.17) show the following. No responses are above 20 seconds on the medium-age dyslexics' terrain. A 'plain' in the 0–5 second range is evident in the lower tables where the quotient is low. Peaks of 15–20 seconds are found on 28 ÷ 7, 48 ÷ 6, 48 ÷ 8, 63 ÷ 9, 72 ÷ 12, 84 ÷ 12 and 96 ÷ 12. The medium-age controls in contrast, make no responses over 15 seconds. Most of the responses are from 0–10 seconds and peaks occur in the same areas as for the medium-age dyslexics, but only at a lower height (faster times).

Comparing old dyslexics with old controls

The old controls are significantly faster than the old dyslexics on all tables except ÷4. For the ÷1, ÷9, ÷10 and ÷12 this difference is at $p < 0.01$, and is at $p < 0.05$ for the remainder. On the ÷12 the mean response time for the old dyslexics was 12.01 seconds compared to 6.58 seconds for the old controls (see Table 11.7). Generally, where the controls took longer, so did the dyslexics.

Comparisons between the topographical terrain diagrams for the two groups (Figures 11.15 and 11.18) show the following. Most response times are in the 5–15 second range for the old dyslexics, with some peaks on 32 ÷ 4, 48 ÷ 6, 96 ÷ 8, 108 ÷ 12, 132 ÷ 11, 84 ÷ 12 and 96 ÷ 12. The terrain for the old controls, in contrast, has large 'plains' in the 0–5 second range with peaks in the 10–15 second range on 36 ÷ 4, 48 ÷ 6, 96 ÷ 8, 108 ÷ 9, 84 ÷ 12 and 96 ÷ 12.

Thus the dyslexics do need more time than non-dyslexics, both in the old age band and more particularly in the young age band.

The topographical terrains that are similar are those for the medium-age dyslexics, old dyslexics and young controls – based on heights, peaks and responses from 0–5 seconds.

Question 2: *Are younger dyslexics slower than older dyslexics?*

The answer to this question is 'yes'.

Young dyslexics compared to medium-age dyslexics

Figure 11.8 clearly shows that the young dyslexics took longer performing division questions at speed than the older age bands. The controls in contrast improved steadily with age (see Figure 11.9 in comparison). The similar shape for the dyslexics and controls in Figure 11.10 illustrates how similar the difference was between the young and medium age bands, but that the difference was significantly greater, shown by post hoc tests, for the dyslexics on all tables, especially ÷2, ÷3, ÷4 and ÷8 ($p < 0.001$). This difference was at $p < 0.05$ on ÷1, ÷10 and ÷11 and the remaining tables were at a significance level of $p < 0.01$. The performance of the young and medium-age controls was statistically similar on all tables except ÷3 ($p < 0.01$) (see Table 11.12) where the medium-age controls were quicker.

Medium-age dyslexics compared to old dyslexics

The medium-age dyslexics were quicker on ÷1, ÷6 and ÷8 than the old dyslexics. No such instances where a younger age band outperformed an older age band were found for the controls. Post hoc t-Tests showed that there was no significant difference between the medium-age dyslexics and the old dyslexics. Likewise the same was found for the control group. The topographical diagrams for the medium-age and old dyslexics are similar with respect to height and terrain. The topographical terrains for the controls showed a larger area of quicker responses (0–5 seconds) for the old controls compared to the medium-age controls.

Young dyslexics compared to old dyslexics

The old dyslexics were faster than the young dyslexics on ÷2, ÷3, ÷4, ÷7 and ÷8 ($p < 0.001$), ÷5, ÷6, ÷9, ÷10, ÷11 and ÷12 ($p < 0.01$) but not on ÷1 (ns). The old controls were also significantly quicker than the young controls on the ÷3, ÷7 and ÷9

($p < 0.001$), ÷1, ÷8 and ÷10 ($p < 0.01$) and ÷2, ÷4, ÷5, ÷6 and ÷12 ($p < 0.05$) but not on ÷11.

Question 3: *Are there any special number combinations that are more likely than others to take more time?*

Several specific division questions have been detailed in answer to Question 1 and 2, as being of a particular challenge to group age bands. A common feature was where the divisor was 8 or 12 and the quotient equalled a higher number (except 10).

'X_D' and 'Y_D' conditions were created as for Division Correct (see Chapter 7) and the mean response time for each condition obtained for each group age band (see Table 11.18 and Figure 11.19). The 'X_D' condition was answered significantly quicker than the 'Y_D' condition by the young controls, young dyslexics and medium-age dyslexics ($p < 0.001$) and for all the other group age bands at a significance level of $p < 0.01$.

An analysis of variance showed a significant difference ($p < 0.01$) on the 'X_D' condition between the dyslexics and non-dyslexics, between the age bands and on the intercept of group and age. Similarly, on the 'Y_D' condition there was a significant difference ($p < 0.001$) between the groups and also age bands but not on the intercept of group and age band. There was no significant difference found on 'Y_D' minus 'X_D'.

Post hoc tests (Tamhane) showed no significant differences between the age bands on the 'X_D' condition but on the 'Y_D' condition the medium age band was significantly quicker than the young age band ($p < 0.01$) although there was no significant difference between the medium and old age bands. No significant difference was found between each of the age bands on 'Y_D' minus 'X_D'. t-Tests showed that the only significant difference between the groups was on the 'X_D' condition ($p < 0.01$) and on the 'Y_D' condition ($p < 0.001$) in the young age band.

Thus the dyslexics did perform significantly slower than the controls on the 'X_D' condition, but this difference was greater on the 'Y_D' condition.

CHAPTER 12

Speed of Addition

12.1 Aims of This Chapter

12.2 Overall Comparisons

12.3 Tasks Within Addition

12.4 Differences Between the Dyslexics and Non-dyslexics on Addition

12.5 Comparing Age Bands Within the Separate Groups

12.6 Order of Difficulty

12.7 Topographical Terrain

12.8 Special Number Combinations in Addition

12.9 Chapter Summary – Questions Answered

12.1 Aims of This chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of addition:

(1) Do dyslexics need more time than non-dyslexics?

(2) Are younger dyslexics slower than older dyslexics?

(3) Are there any special number combinations that are more likely than others to take more time?

12.2 Overall Comparisons

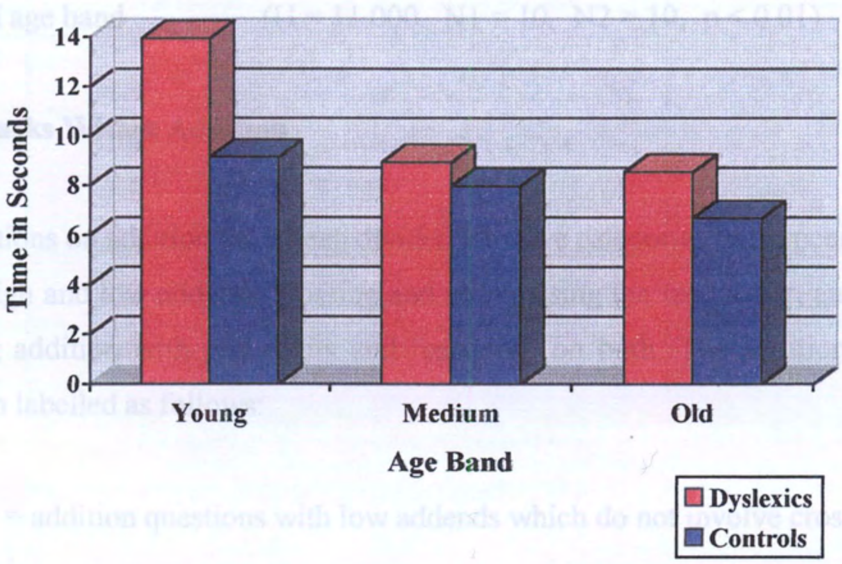
All the addition response times were combined and a comparison was drawn up between the two experimental groups and the three age bands.

The mean and median response times (in seconds) and standard deviations are given for groups and age bands in Table 12.1. The results for mean response times are illustrated in Figure 12.1.

Table 12.1 Mean, standard deviation and median response times (in seconds) by group and age on addition

Groups	*Age band*	*Mean*	*Standard deviation*	*Median*
Dyslexics	Young	13.94	2.50	13.12
	Medium	8.94	1.03	9.27
	Old	8.54	1.51	8.54
Controls	Young	9.14	1.28	9.43
	Medium	7.97	1.70	8.02
	Old	6.66	0.74	6.41

Figure 12.1 Mean response time by group and age on addition



Analysis of variance shows the following overall results (see Appendix F7 for tables):

The main effect for age on response time was significant ($F\ (2,54) = 35.085$, $p < 0.001$). The older participants took significantly less time to respond than the younger ones.

The main effect of group (dyslexics, controls) was significant ($F\ (1,54) = 39.881$, $p < 0.001$).

There was a significant interaction between group and age ($F\ (2,54) = 8.188$, $p < 0.001$).

Post hoc testing (age band of participants) using Tamhane gave a significant difference between the young and medium age band ($p < 0.001$) and the young and old age band ($p < 0.001$) but not the medium and old age band (ns).

In order to compare the dyslexics with non-dyslexics in each age band, a Mann-Whitney Test was conducted. This showed the following:

- Young age band ($U = 14.000$, $N1 = 10$, $N2 = 10$, $p < 0.01$)
- Medium age band ($U = 33.000$, $N1 = 10$, $N2 = 10$, ns)
- Old age band ($U = 11.000$, $N1 = 10$, $N2 = 10$, $p < 0.01$)

12.3 Tasks Within Addition

The questions on addition have been divided into five categories with special attention paid to high and low addends crossing and not crossing the ten barrier, and questions involving addition with two digits and 'carrying' on both. The addition categories have been labelled as follows:

- LN = addition questions with low addends which do not involve crossing the ten barrier.

- HN = addition questions with high addends which do not involve crossing the ten barrier.
- LC = addition questions with low addends which involve crossing the ten barrier.
- HC = addition questions with high addends which involve crossing the ten barrier.
- HARD = 'hard' questions involving addition with two digits and 'carrying' from the units to the tens.

The results are given for each age band in turn.

An analysis of variance was carried out on group and age band performance on each of the addition categories. The results are displayed in Table 12.2. Comparisons between the groups and age bands are made in post hoc tests presented in Tables 12.3 and 12.4 respectively.

Table 12.2 Analysis of variance results (between-subjects effects) showing significant differences in mean response times between groups, age bands and the intercept of groups and age bands

Category	*Groups*	*Age bands*	*Group and age band*
LN	34.749***	32.926***	9.947***
HN	36.293***	38.141***	11.671***
LC	41.257***	36.438***	12.570***
HC	47.274***	35.655***	9.711***
HARD	10.245**	8.612***	0.944 ns
	F (1,54)	F (2,54)	F (2,54)

Significance levels key for Tables 12.2, 12.3 and 12.4 :

*** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

Table 12.3 Post hoc tests (Mann-Whitney U) between groups

Addition category	*Group comparisons in each age band*		
	Young	*Medium*	*Old*
LN	3.000***	23.000*	12.000**
HN	3.000***	25.000 (ns)	11.000**
LC	0.000***	18.000*	14.000**
HC	1.000***	19.000*	14.000**
HARD	24.000*	40.000 (ns)	15.000**

Table 12.4 Post hoc tests (multiple comparisons – Tamhane) between age bands

Addition category	*Age band comparisons*		
	Y/M	*Y/O*	*M/O*
LN	**	***	*
HN	**	***	*
LC	**	***	ns
HC	**	***	ns
HARD	*	**	ns

Key: Y (young), M (medium-age), O (old).

The mean response times for groups on addition categories are given for each age band in turn. These are presented in Tables 12.5, 12.6 and 12.7 and illustrated in Figures 12.2, 12.3 and 12.4.

Table 12.5 Mean response times for each group and addition category in the young age band (standard deviation given in brackets)

Addition category	*Young dyslexics*		*Young controls*	
LN	9.04	(2.58)	4.65	(1.15)
HN	9.32	(2.50)	4.77	(1.20)
LC	11.09	(3.38)	5.20	(0.99)
HC	12.81	(2.99)	6.71	(1.55)
HARD	13.16	(4.79)	10.25	(2.21)

Figure 12.2 Mean response times for each group and addition category in the young age band

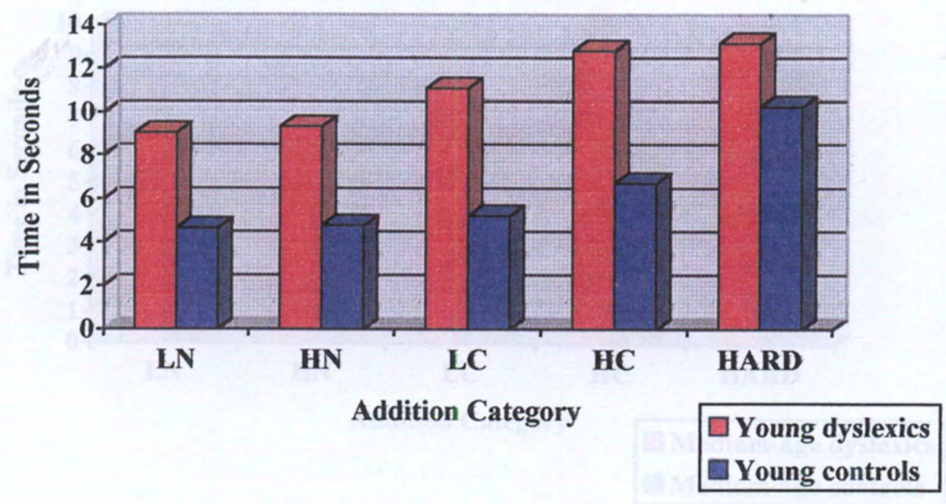


Table 12.6 Mean response times for each group and addition category in the medium age band (standard deviation given in brackets)

Addition category	*Medium-age dyslexics*		*Medium-age controls*	
LN	4.70	(0.75)	3.86	(1.37)
HN	4.62	(0.61)	3.92	(1.54)
LC	5.03	(0.92)	4.07	(1.20)
HC	6.97	(1.15)	5.58	(1.73)
HARD	9.26	(2.46)	8.29	(2.88)

Figure 12.3 Mean response times for each group and addition category in the medium age band

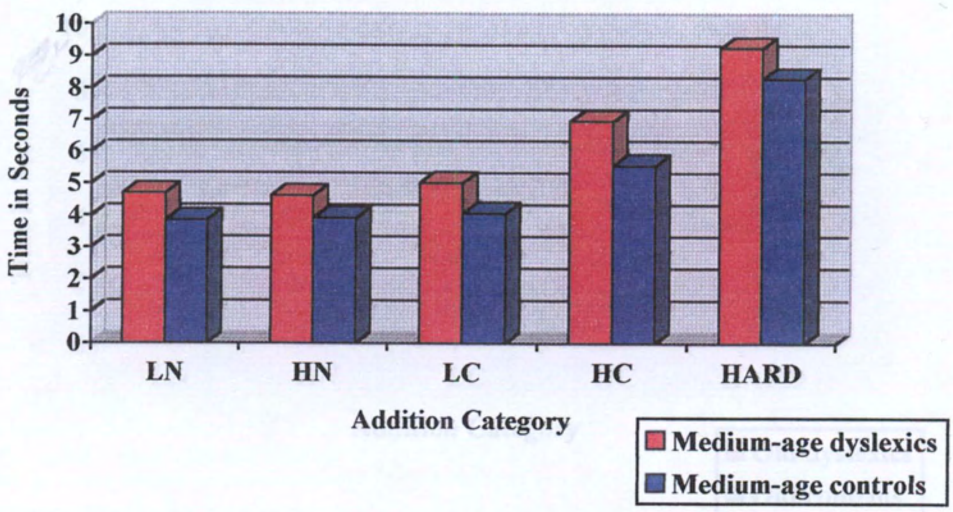
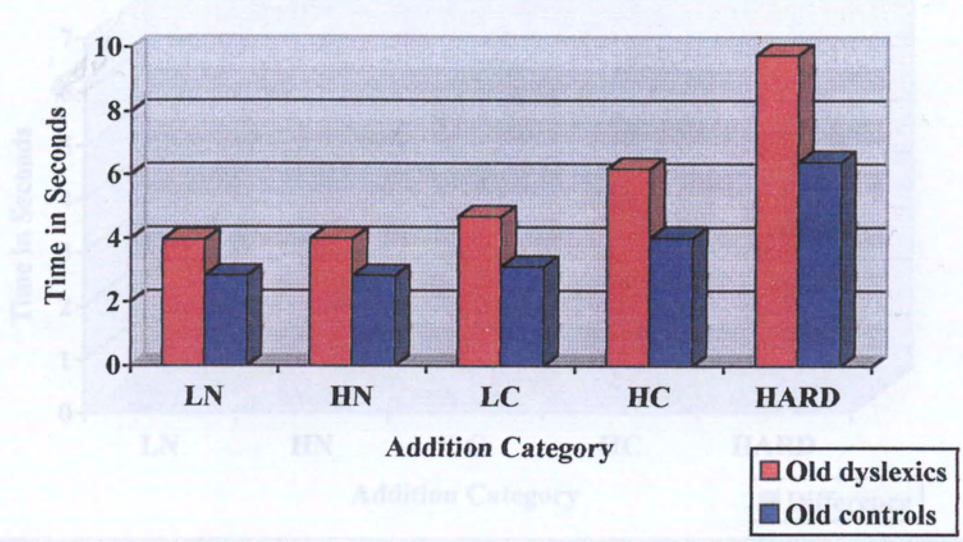


Table 12.7 Mean response times for each group and addition category in the old age band (standard deviation given in brackets)

Addition category	*Old dyslexics*		*Old controls*	
LN	3.96	(1.02)	2.82	(0.52)
HN	3.99	(0.84)	2.82	(0.48)
LC	4.68	(1.48)	3.10	(0.60)
HC	6.18	(1.81)	4.02	(0.91)
HARD	9.77	(2.71)	6.40	(1.39)

Figure 12.4 Mean response times for each group and addition category in the old age band



12.4 Differences Between the Dyslexics and Non-dyslexics on Addition

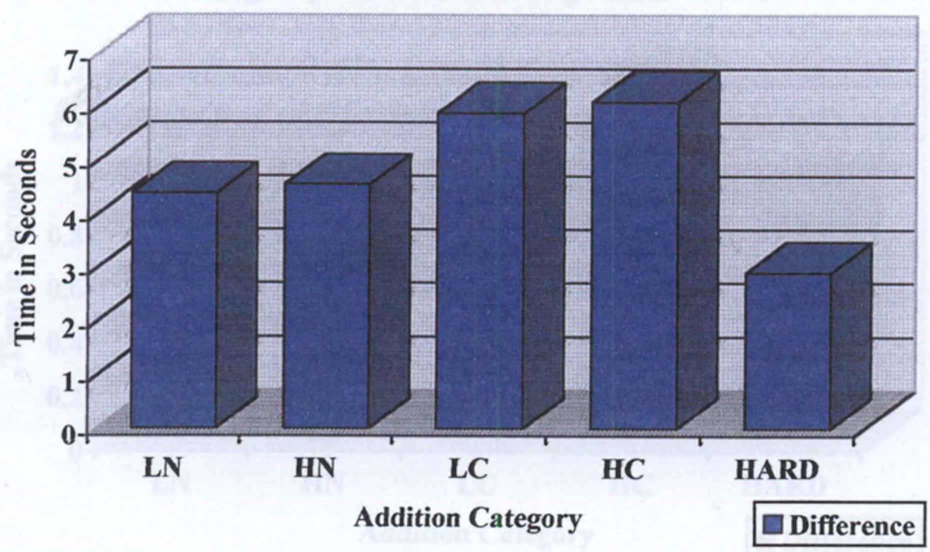
The information in this section does not display new data but draws on the results found in section 12.3. This section enables the reader to analyse the differences found in the mean times between the two experimental groups.

Firstly, a study was made of the difference between the groups in the young age band. See Table 12.5 for the main results from which the 'Difference' in Table 12.8 was drawn. This difference is illustrated in Figure 12.5.

Table 12.8 Differences in mean response times (in seconds) between the dyslexic and control groups in the young age band

	Addition category				
	LN	*HN*	*LC*	*HC*	*HARD*
Difference	4.39	4.55	5.89	6.1	2.91

Figure 12.5 Differences in mean response times between the groups in the young age band



The positive results indicated that the control group was quicker on all the addition categories.

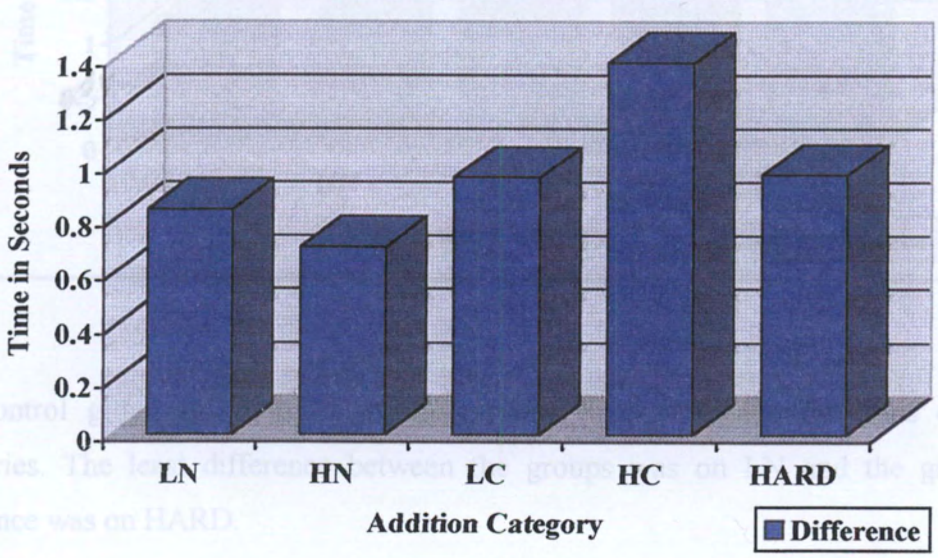
The difference was greatest on LC, HC with a recorded time difference of greater than 5 seconds. The smallest difference occurred on the HARD category.

Secondly, a study was made of the difference between the groups in the medium age band. See Table 12.6 for the main results from which the 'Difference' in Table 12.9 was drawn. This difference is illustrated in Figure 12.6.

Table 12.9 Differences in mean response times (in seconds) between the dyslexic and control groups in the medium age band

	Addition category				
	LN	*HN*	*LC*	*HC*	*HARD*
Difference	0.84	0.7	0.96	1.39	0.97

Figure 12.6 Differences in mean response times between the groups in the medium age band



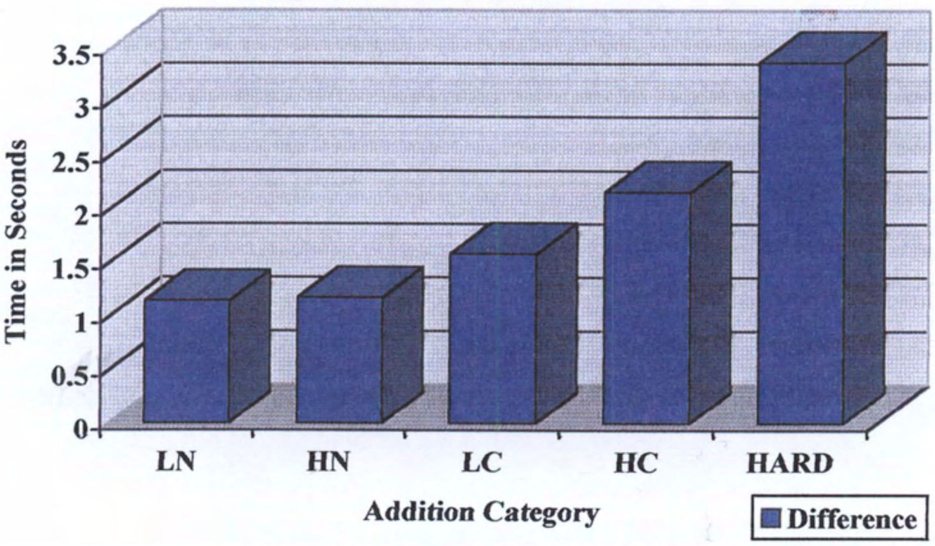
The control group has quicker mean response times for all categories than the dyslexics. The smallest difference is on HN and the greatest difference is on HC.

Thirdly, a study was made of the difference between the groups in the old age band. See Table 12.7 for the main results from which the 'Difference' in Table 12.10 was drawn. This difference is illustrated in Figure 12.7.

Table 12.10 Differences in mean response times (in seconds) between the dyslexic and control groups in the old age band

	Addition category				
	LN	*HN*	*LC*	*HC*	*HARD*
Difference	1.14	1.17	1.58	2.16	3.37

Figure 12.7 Differences in mean response times between the groups in the old age band



The control group had quicker mean response times than the dyslexics on all categories. The least difference between the groups was on LN and the greatest difference was on HARD.

12.5 Comparing Age Bands Within the Separate Groups

Is the difference between the age bands the same for both groups or are the dyslexics different? Does the speed of response to addition questions improve with age for both groups?

The information in this section does not display new data but draws on the results found in section 12.3. This section enables the reader to compare age band performance within the separate groups.

The mean response time on each category is recorded in Figure 12.8 for each of the dyslexic age bands. Figure 12.9 gives the results for each of the control age bands. Both figures have been placed together for ease of comparison between the performance of the dyslexic and non-dyslexic groups.

Figure 12.8 Mean response time (seconds) for the three dyslexic age bands on all categories.

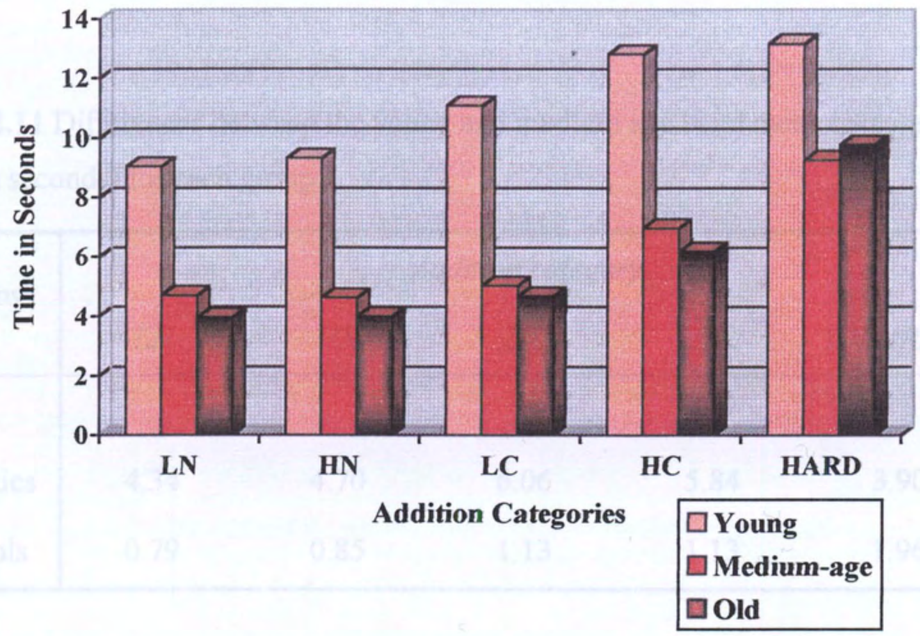
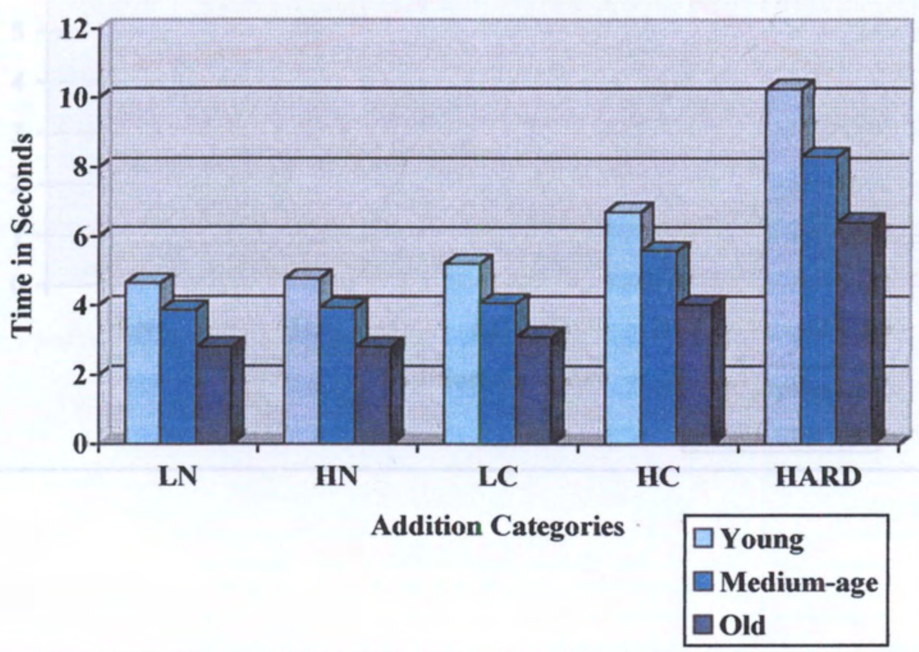


Figure 12.9 Mean response time (seconds) for the three control age bands on all categories.



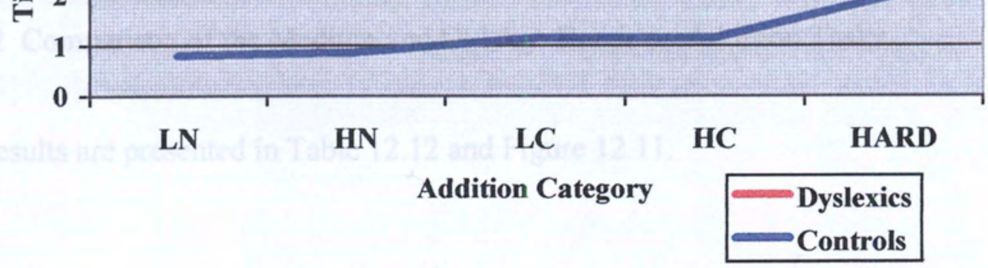
12.5.1 Comparison of the Young and Medium Age bands on Addition Tasks

The results are presented in Table 12.11 and Figure 12.10.

Table 12.11 Differences between the young and medium age band mean response times (in seconds) for each group

Groups	*Addition category*				
	LN	*HN*	*LC*	*HC*	*HARD*
Dyslexics	4.34	4.70	6.06	5.84	3.90
Controls	0.79	0.85	1.13	1.13	1.96

Figure 12.10 Differences between the young and medium age band mean response times (in seconds) for each group



t-Tests comparing the young and medium age bands in each group show:

Dyslexic group:

- LN ($t = 5.120$, $df = 18$, $p < 0.001$)
- HN ($t = 5.778$, $df = 18$, $p < 0.001$)
- LC ($t = 5.469$, $df = 18$, $p < 0.001$)
- HC ($t = 5.772$, $df = 18$, $p < 0.001$)
- HARD ($t = 2.288$, $df = 18$, $p < 0.05$)

Control group:

- LN ($t = 1.401$, $df = 18$, ns)
- HN ($t = 1.370$, $df = 18$, ns)
- LC ($t = 2.287$, $df = 18$, $p < 0.05$)
- HC ($t = 1.539$, $df = 18$, ns)
- HARD ($t = 1.706$, $df = 18$, ns)

A positive score in Table 12.11 indicates that the medium age band have quicker mean response times than the young age band. In a comparison of group performance, the control group shows the least difference in the scores between the young and medium age band than the dyslexics, on each category.

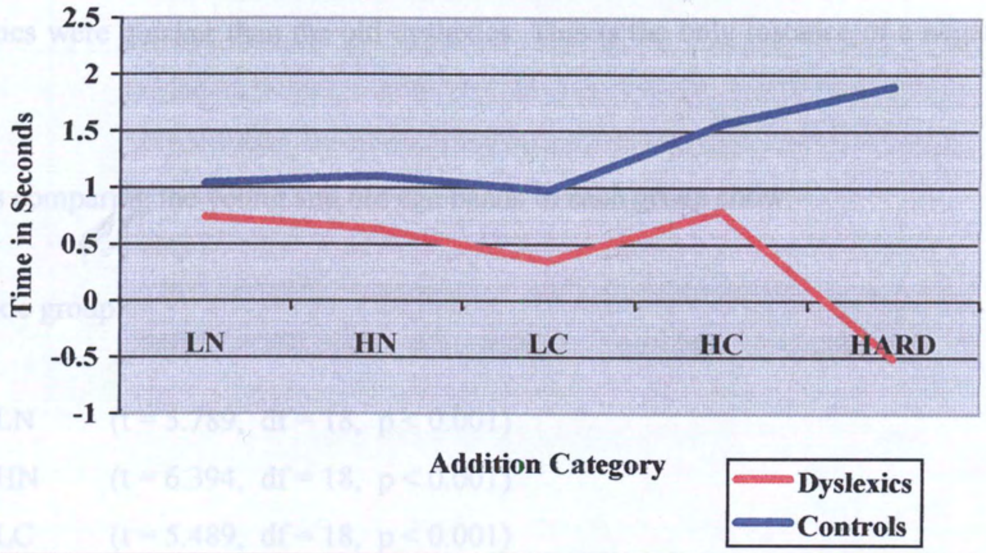
12.5.2 Comparison of the Medium and Old Age Bands on Addition Tasks

The results are presented in Table 12.12 and Figure 12.11.

Table 12.12 Differences between the medium and old age band mean response times (in seconds) for each group

Groups	*Addition category*				
	LN	*HN*	*LC*	*HC*	*HARD*
Dyslexics	0.74	0.63	0.35	0.79	–0.51
Controls	1.04	1.1	0.97	1.56	1.89

Figure 12.11 Differences between the medium and old age band mean response times (in seconds) for each group



t-Tests comparing the medium and old age bands in each group show:

Dyslexic group:

- LN (t = 1.829, df = 18, ns)
- HN (t = 1.918, df = 18, ns)
- LC (t = 0.622, df = 18, ns)
- HC (t = 1.155, df = 18, ns)
- HARD (t = 0.436, df = 18, ns)

Control group:

- LN $(t = 2.228,\ df = 18,\ p < 0.05)$
- HN $(t = 2.153,\ df = 18,\ p < 0.05)$
- LC $(t = 2.289,\ df = 18,\ p < 0.05)$
- HC $(t = 2.516,\ df = 18,\ p < 0.05)$
- HARD $(t = 1.874,\ df = 18,$ ns)

A positive score in Table 12.12 indicates that the old age band have quicker mean response times than the medium age band; this is found in all but one category. A negative score indicates that this is vice versa. In a comparison of group performance, the dyslexic group show less difference in the scores between the medium and old age band than the controls, on each category. In the HARD category the medium dyslexics were quicker than the old dyslexics. This is the only instance of a negative score.

t-Tests comparing the young and old age bands in each group show:

Dyslexic group:

- LN $(t = 5.789,\ df = 18,\ p < 0.001)$
- HN $(t = 6.394,\ df = 18,\ p < 0.001)$
- LC $(t = 5.489,\ df = 18,\ p < 0.001)$
- HC $(t = 5.996,\ df = 18,\ p < 0.001)$
- HARD $(t = 1.948,\ df = 18,$ ns)

Control group:

- LN $(t = 4.581,\ df = 18,\ p < 0.001)$
- HN $(t = 4.776,\ df = 18,\ p < 0.001)$
- LC $(t = 5.746,\ df = 18,\ p < 0.001)$
- HC $(t = 4.729,\ df = 18,\ p < 0.001)$
- HARD $(t = 4.662,\ df = 18,\ p < 0.001)$

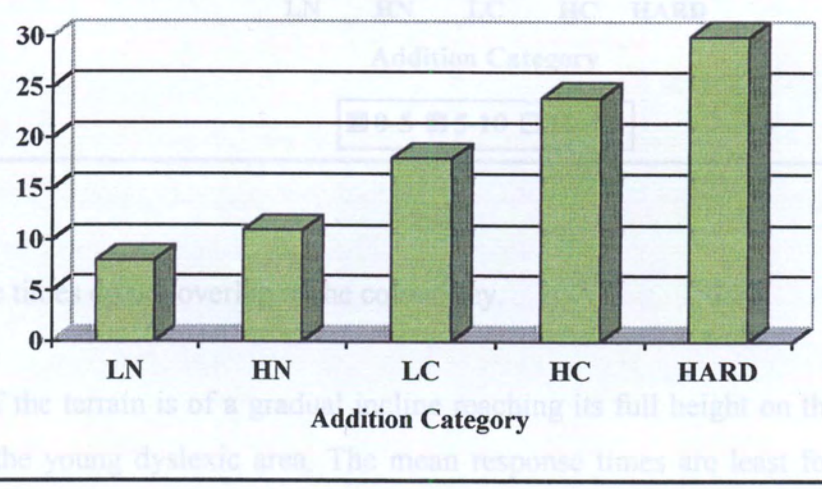
12.6 Order of Difficulty

The results displayed in Tables 12.5, 12.6 and 12.7 show the mean response times for groups and age bands on each addition category. Table 12.13 shows the order of difficulty of the addition categories for each group and age band found from these Tables. The ranks have been totalled and the 'overall rank' found from these. The results are illustrated in Figure 12.12.

Table 12.13 Order of difficulty for the five addition categories

Addition category	*Dyslexics*			*Controls*			*Total*	*Overall rank*
	Age band							
	Young	*Medium*	*Old*	*Young*	*Medium*	*Old*		
LN	1	2	1	1	1	1.5	8	1
HN	2	1	2	2	2	1.5	11	2
LC	3	3	3	3	3	3	18	3
HC	4	4	4	4	4	4	24	4
HARD	5	5	5	5	5	5	30	5

Figure 12.12 Addition category total rank scores for all groups and age bands combined



If the criterion is speed of performing addition, the order of difficulty for the addition categories is LN, HN, LC, HC and HARD

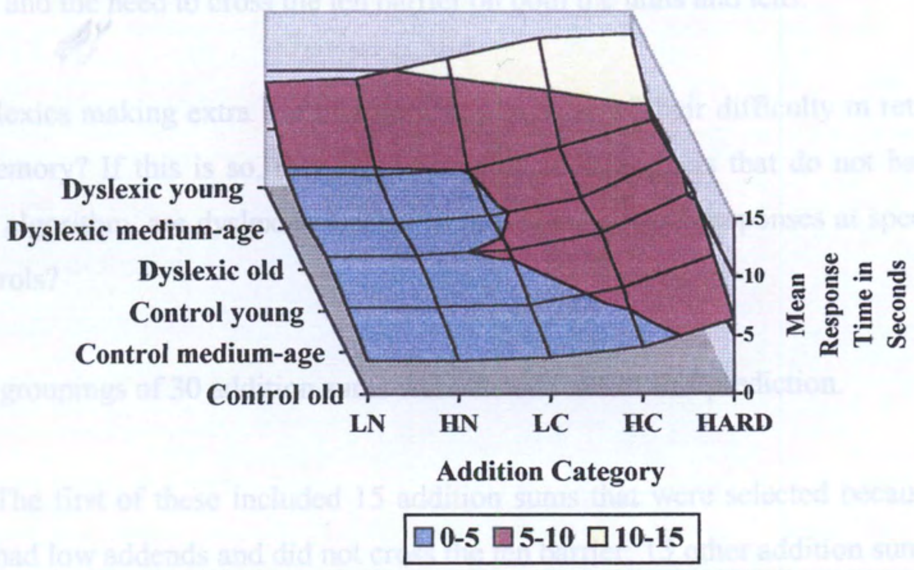
Spearman's non-parametric correlation showed that the order for the groups and age bands are significantly the same.

- Spearman rho = 0.9703, $p < 0.001$

12.7 Topographical Terrain

The topographical terrain displayed in Figure 12.13 is composed of the mean response times found on each category for the dyslexics and controls in the three age bands.

Figure 12.13 Topographical terrain for the mean response time (in seconds) for group and age band on addition categories



The response times do not overlap in the colour key.

The shape of the terrain is of a gradual incline reaching its full height on the HARD category in the young dyslexic area. The mean response times are least for the old controls on LN, HN and LC. The old dyslexics perform similarly to the medium-age controls and likewise the medium-age dyslexics perform similarly to the young controls. Thus the dyslexic scores resemble those of the controls who are in a younger age band.

12.8 Special Number Combinations in Addition

This section is designed specifically to answer question 3 posed at the start of the chapter. Are there any special number combinations for addition that are more likely than others to take more time?

Which addition combinations do the dyslexics find the hardest to respond to quickly? In the case of addition facts that involve extra algorithms (steps), are dyslexics weaker at responding quickly when compared to the controls?

Addition has been divided into questions with high/low addends, questions that do and do not cross the ten barrier and finally questions that have a combination of high addends and the need to cross the ten barrier on both the units and tens.

Are dyslexics making extra use of algorithms because of their difficulty in retrieving from memory? If this is so, then in the case of addition facts that do not have any obvious algorithm, are dyslexics weaker at producing correct responses at speed than the controls?

Several groupings of 30 addition sums were chosen to test this prediction.

(1) The first of these included 15 addition sums that were selected because they had low addends and did not cross the ten barrier; 15 other addition sums were included because they had low addends and crossed the ten barrier. LN versus LC represents this. See Table 12.14.

Table 12.14 Mean response times (in seconds) by groups and age bands in the LN and LC type condition for addition

Groups and age bands	*LN condition*	*LC condition*
Young age band		
Dyslexics	9.04	11.09
Controls	4.65	5.20
Medium age band		
Dyslexics	4.70	5.03
Controls	3.86	4.07
Old age band		
Dyslexics	3.96	4.68
Controls	2.82	3.10

t-Test results on paired samples LN and LC for groups and age bands are as follows:

- Young controls $t = 2.278$, $df = 9$, $p < 0.05$
- Young dyslexics $t = 5.361$, $df = 9$, $p < 0.001$
- Medium-age controls $t = 1.854$, $df = 9$, ns
- Medium-age dyslexics $t = 2.636$, $df = 9$, $p < 0.05$
- Old controls $t = 4.553$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 3.899$, $df = 9$, $p < 0.01$

Tests of between-subjects effects on LN gave a significant difference between groups ($F (1,54) = 34.749$, $p < 0.001$) and age bands ($F (2,54) = 32.926$, $p < 0.001$) and the intercept of group and age band ($F (2,54) = 9.947$, $p < 0.001$).

Tests of between-subjects effects on LC gave a significant difference between groups ($F (1,54) = 41.257$, $p < 0.001$) and age bands ($F (2,54) = 36.438$, $p < 0.001$) and the intercept of group and age band ($F (2,54) = 12.570$, $p < 0.001$).

(2) The second of these included 15 addition sums that were selected because they had high addends and did not cross the ten barrier; 15 other addition sums were included because they had high addends and crossed the ten barrier. HN versus HC represents this. See Table 12.15.

Table 12.15 Mean response times (in seconds) by groups and age bands in the HN and HC type condition for addition

Groups and age bands	*HN condition*	*HC condition*
Young age band		
Dyslexics	9.32	12.81
Controls	4.77	6.71
Medium age band		
Dyslexics	4.62	6.97
Controls	3.92	5.58
Old age band		
Dyslexics	3.99	6.18
Controls	2.82	4.02

t-Test results on paired samples HN and HC for groups and age bands are as follows:

- Young controls $t = 6.033$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 7.249$, $df = 9$, $p < 0.001$
- Medium-age controls $t = 6.151$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 8.342$, $df = 9$, $p < 0.001$
- Old controls $t = 6.233$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 6.438$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on HN give a significant difference between groups ($F (1,54) = 36.293$, $p < 0.001$) and age bands ($F (2,54) = 38.141$, $p < 0.001$) and the intercept of group and age band ($F (2,54) = 11.671$, $p < 0.001$).

Tests of between-subjects effects on HC show that there is a significant difference between groups ($F (1,54) = 47.274$, $p < 0.001$) and age bands ($F (2,54) = 35.655$, $p < 0.001$) and a significant difference between the intercept of group and age band ($F (2,54) = 9.711$, $p < 0.001$).

(3) The third of these included 15 addition sums that were selected because they had low addends and did not cross the ten barrier and 15 other addition sums were included because they had high addends and did not cross the ten barrier. LN versus HN represents this. See Table 12.16.

Table 12.16 Mean response times (in seconds) by groups and age bands in the LN and HN type condition for addition

Groups and age bands	*LN condition*	*HN condition*
Young age band		
Dyslexics	9.04	9.32
Controls	4.65	4.77
Medium age band		
Dyslexics	4.70	4.62
Controls	3.86	3.92
Old age band		
Dyslexics	3.96	3.99
Controls	2.82	2.82

t-Test results on paired samples LN and HN for groups and age bands are as follows:

- Young controls $t = 0.878$, $df = 9$, ns
- Young dyslexics $t = 1.341$, $df = 9$, ns
- Medium-age controls $t = 0.374$, $df = 9$, ns
- Medium-age dyslexics $t = 0.460$, $df = 9$, ns
- Old controls $t = 0.035$, $df = 9$, ns
- Old dyslexics $t = 0.168$, $df = 9$, ns

Tests of between-subjects effects on LN give a significant difference between groups ($F(1,54) = 34.749$, $p < 0.001$) and age bands ($F(2,54) = 32.926$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 9.947$, $p < 0.001$).

Tests of between-subjects effects on HN give a significant difference between groups ($F(1,54) = 36.293$, $p < 0.001$) and age bands ($F(2,54) = 38.141$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 11.671$, $p < 0.001$).

(4) The fourth of these included 15 addition sums that were selected because they had low addends and crossed the ten barrier; 15 other addition sums were included because they had high addends and crossed the ten barrier. LC versus HC represents this. See Table 12.17.

Table 12.17 Mean response times (in seconds) by groups and age bands in the LC and HC type condition for addition

Groups and age bands	*LC condition*	*HC condition*
Young age band		
Dyslexics	11.09	12.81
Controls	5.19	6.71
Medium age band		
Dyslexics	5.03	6.97
Controls	4.07	5.58
Old age band		
Dyslexics	4.68	6.18
Controls	3.10	4.02

t-Test results on paired samples LC and HC for groups and age bands are as follows:

- Young controls $t = 5.845$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 3.750$, $df = 9$, $p < 0.01$
- Medium-age controls $t = 7.213$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 7.763$, $df = 9$, $p < 0.001$
- Old controls $t = 7.489$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 8.971$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LC gave a significant difference between groups ($F (1,54) = 41.257$, $p < 0.001$) and age bands ($F (2,54) = 36.438$, $p < 0.001$) and the intercept of group and age band ($F (2,54) = 12.570$, $p < 0.001$).

Tests of between-subjects effects on HC show that there is a significant difference between groups ($F (1,54) = 47.274$, $p < 0.001$) and age bands ($F (2,54) = 35.655$,

$p < 0.001$) and a significant difference between the intercept of group and age band ($F(2,54) = 9.711$, $p < 0.001$).

(5) The fifth of these included 15 addition sums that were selected because they had high addends and did not cross the ten barrier; 15 other addition sums were included because they had low addends and crossed the ten barrier. HN versus LC represents this. See Table 12.18.

Table 12.18 Mean response times (in seconds) by groups and age bands in the HN and LC type condition for addition

Groups and age bands	*HN condition*	*LC condition*
Young age band		
Dyslexics	9.32	11.09
Controls	4.77	5.19
Medium age band		
Dyslexics	4.62	5.03
Controls	3.92	4.07
Old age band		
Dyslexics	3.99	4.68
Controls	2.82	3.10

t-Test results on paired samples HN and LC for groups and age bands are as follows:

- Young controls $t = 1.465$, $df = 9$, ns
- Young dyslexics $t = 4.368$, $df = 9$, $p < 0.01$
- Medium-age controls $t = 0.711$, $df = 9$, ns
- Medium-age dyslexics $t = 2.355$, $df = 9$, $p < 0.05$
- Old controls $t = 2.783$, $df = 9$, $p < 0.05$
- Old dyslexics $t = 2.764$, $df = 9$, $p < 0.05$

Tests of between-subjects effects on HN give a significant difference between groups (F (1,54) = 36.293, $p < 0.001$) and age bands (F (2,54) = 38.141, $p < 0.001$) and the intercept of group and age band (F (2,54) = 11.671, $p < 0.001$).

Tests of between-subjects effects on LC gave a significant difference between groups (F (1,54) = 41.257, $p < 0.001$) and age bands (F (2,54) = 36.438, $p < 0.001$) and the intercept of group and age band (F (2,54) = 12.570, $p < 0.001$).

(6) The sixth of these included 15 addition sums that were selected because they had low addends and did not cross the ten barrier; 15 other addition sums were included because they had high addends, a two-digit number added to a two-digit number and crossed the ten barrier. LN versus HARD represents this. See Table 12.19.

Table 12.19 Mean response times (in seconds) by groups and age bands in the LN and HARD type condition for addition

Groups and age bands	*LN condition*	*HARD condition*
Young age band		
Dyslexics	9.04	13.16
Controls	4.65	10.25
Medium age band		
Dyslexics	4.70	9.26
Controls	3.86	8.29
Old age band		
Dyslexics	3.96	9.77
Controls	2.82	6.40

t-Test results on paired samples LN and HARD for groups and age bands are as follows:

- Young controls $t = 10.198$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 2.334$, $df = 9$, $p < 0.05$
- Medium-age controls $t = 8.047$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 6.729$, $df = 9$, $p < 0.001$
- Old controls $t = 11.692$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 9.451$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LN give a significant difference between groups ($F(1,54) = 34.749$, $p < 0.001$) and age bands ($F(2,54) = 32.926$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 9.947$, $p < 0.001$).

Tests of between-subjects effects on HARD show that there is a significant difference between groups ($F(1,54) = 10.245$, $p < 0.01$) and age bands ($F(2,54) = 8.612$, $p < 0.001$) but no significant difference was found between the intercept of group and age band ($F(2,54) = 0.944$, ns).

(7) The seventh of these included 30 addition sums that were selected because they had low / high addends and did not cross the ten barrier and 30 other addition sums were included because they had low / high addends and crossed the ten barrier. This is represented by LN/HN versus LC/HC. See Table 12.20.

Table 12.20 Mean response times (in seconds) by groups and age bands in the LN/HN and LC/HC type condition for addition

Groups and age bands	*LN/HN condition*	*LC/HC condition*
Young age band		
Dyslexics	9.18	11.95
Controls	4.71	5.95
Medium age band		
Dyslexics	4.66	6.00
Controls	3.89	4.82
Old age band		
Dyslexics	3.98	5.43
Controls	2.82	3.56

t-Test results on paired samples LN / HN versus LC / HC for groups and age bands are as follows:

- Young controls $t = 5.054$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 7.594$, $df = 9$, $p < 0.001$
- Medium-age controls $t = 5.725$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 7.862$, $df = 9$, $p < 0.001$
- Old controls $t = 6.587$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 5.591$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LN/HN give a significant difference between groups ($F(1,54) = 36.697$, $p < 0.001$) and age bands ($F(2,54) = 36.648$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 11.142$, $p < 0.001$).

Tests of between-subjects effects on LC/HC show that there is a significant difference between groups ($F\ (1,54) = 46.978$, $p < 0.001$), and age bands ($F\ (2,54) = 38.102$, $p < 0.001$) and the intercept of group and age band ($F\ (2,54) = 11.705$, $p < 0.001$).

(8) The eighth of these included 30 addition sums that were selected because they has low addends; 30 other addition sums were included because they had high addends. This is represented by LN/LC versus HN/HC. See Table 12.21.

Table 12.21 Mean response times (in seconds) by groups and age bands in the LN/LC and HN/HC type condition for addition

Groups and age bands	*LN/LC condition*	*HN/HC condition*
Young age band		
Dyslexics	10.06	11.06
Controls	4.92	5.74
Medium age band		
Dyslexics	4.86	5.79
Controls	3.96	4.75
Old age band		
Dyslexics	4.32	5.09
Controls	2.96	3.42

t-Test results on paired samples LN/LC and HN/HC for groups and age bands are as follows:

- Young controls $t = 5.421$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 3.747$, $df = 9$, $p < 0.01$
- Medium-age controls $t = 5.457$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 5.691$, $df = 9$, $p < 0.001$

- Old controls $t = 8.049$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 5.743$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LN/LC give a significant difference between groups ($F (1,54) = 15.636$, $p < 0.001$) and age bands ($F (2,54) = 12.904$, $p < 0.001$) and the intercept of group and age band ($F (2,54) = 5.815$, $p < 0.01$).

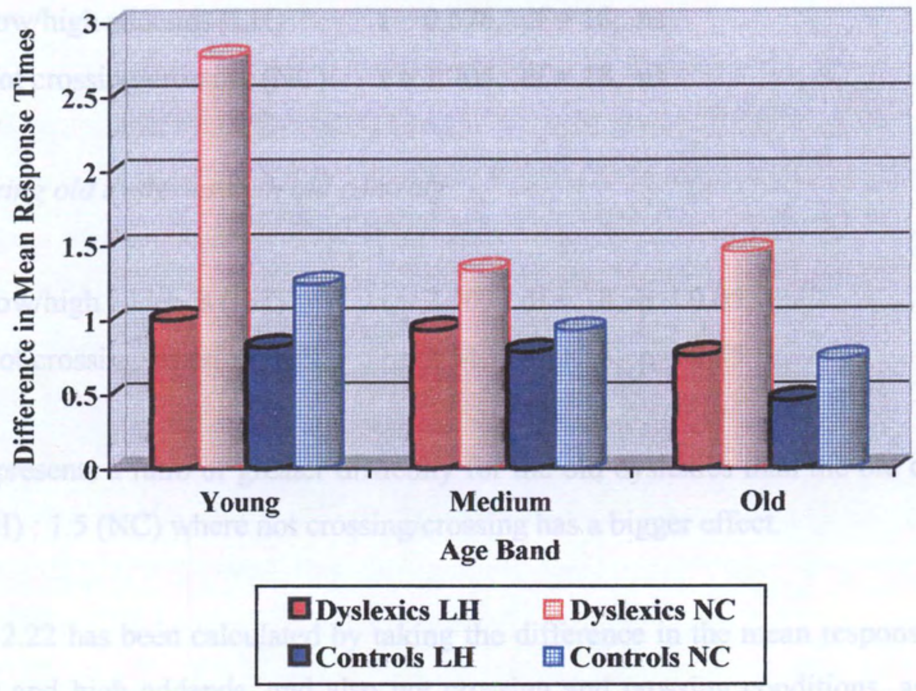
Tests of between-subjects effects on HN/HC show that there is a significant difference between groups ($F (1,54) = 16.431$, $p < 0.001$) and age bands ($F (2,54) = 5.138$, $p < 0.01$) but no significant difference between the intercept of group and age band ($F (2,54) = 0.897$, ns).

12.8.1 Comparing Low/High Addends with Not Crossing/Crossing the Ten Barrier

Which number combination has more effect - the low/high addends, or not crossing/crossing the ten barrier? Is there a difference between the groups and, if so, in which age bands?

The mean response times for both low addends and high addends (LH) were compared for all group age bands and the difference found. The same was done for not crossing and crossing (NC) mean response times. The results are displayed in Figure 12.14.

Figure 12.14 Difference in mean response times on LH and NC by group and age band.



A comparison of *all* controls with *all* dyslexics (ages combined) gave the following t-Test results:

- Low/high addends $t = 1.583$, $df = 58$, ns
- Not crossing/crossing $t = 3.945$, $df = 58$, $p < 0.001$

Comparing young dyslexics with young controls

- Low/high addends (LH) $t = 0.610$, $df = 18$, ns
- Not crossing/crossing (NC) $t = 3.470$, $df = 18$, $p < 0.01$

This represents a ratio of greater difficulty for the young dyslexics than the young controls of 1 (LH) : 5.25 (NC) where not crossing/crossing has a bigger effect.

Comparing medium-age dyslexics with medium-age controls

- Low/high addends (LH) $t = 0.676$, $df = 18$, ns
- Not crossing/crossing (NC) $t = 1.705$, $df = 18$, ns

Comparing old dyslexics with old controls

- Low/high addends (LH) $t = 2.103$, $df = 18$, $p < 0.05$
- Not crossing/crossing (NC) $t = 2.543$, $df = 18$, $p < 0.05$

This represents a ratio of greater difficulty for the old dyslexics than the old controls of 1 (LH) : 1.5 (NC) where not crossing/crossing has a bigger effect.

Table 12.22 has been calculated by taking the difference in the mean response times for low and high addends, and also not crossing and crossing conditions, and then comparing this difference between the groups. In each case the difference in the mean response times for the dyslexics was greater than the controls. Entries in bold indicate which of the conditions was more quickly answered. A ratio of difficulty of the conditions is presented.

Table 12.22 Percentage difference between the groups when comparing the difference in mean response times between the LH and NC conditions.

Condition	*Age band*		
	Young	*Medium*	*Old*
Low/high addends	23%	19%	66%
Not crossing/crossing	123%	43%	98%
Ratio of difficulty	1 : 5.25	1 : 2.23	1 : 1.5

12.9 Chapter Summary – Questions Answered

Question 1: *Do dyslexics need more time than non-dyslexics?*

The answer to this question is 'yes'.

An analysis of variance on the mean response time showed that the dyslexics were significantly slower than the controls ($p < 0.001$). Older participants took significantly less time to respond than the younger ones ($p < 0.001$) and there was a significant interaction between group and age ($p < 0.001$). Post hoc tests (Tamhane) showed that the young age band was significantly slower than the medium age band ($p < 0.001$) but there was no significant difference between the medium and old age band. A Mann-Whitney test showed that the controls were significantly better than the dyslexics in both the young and old age bands ($p < 0.01$).

Spearman's non-parametric correlation showed that the order of difficulty of the five addition categories for the group and age bands was significantly the same (Spearman rho = 0.9703, $p < 0.001$). The addition categories can be ordered (from fastest to slowest) as: LN, HN, LC, HC and HARD. Thus categories that did not cross the ten barrier were responded to more quickly for both low and high addends. Thus the HN category was quicker on the whole than the response time on LC.

An analysis of variance (presented in Table 12.2) on the mean response time for participants on each of the categories showed that the non-dyslexics were significantly faster than the dyslexics on all categories ($p < 0.001$) with HARD having a significance level of $p < 0.01$. There were very highly significant differences between the age bands on all categories, with similar results on the intercept of group and age band except for HARD for which there were non-significant findings. On post hoc tests (Tamhane) the young age band was significantly slower than the medium age band on all categories ($p < 0.01$) and on HARD the significance level was $p < 0.05$. The LN and HN categories were the only addition categories where the old age band was significantly faster than the medium age band.

Comparing young dyslexics to young controls

Group comparisons (Mann-Whitney 'U' tests presented in Table 12.3) showed that the greatest significant difference was in the young age band where the controls answered significantly faster in all categories ($p < 0.001$) including HARD ($p < 0.05$). The mean response time on LN by the young dyslexics was 9.04 seconds compared to 4.65 seconds by the young controls. On HC the mean response time for the dyslexics was 6.1 seconds more than that for the controls. On all categories except HARD (2.91 seconds) the dyslexic mean response time was over 4 seconds longer than the controls.

The topographical terrain (Figure 12.13) shows that the young dyslexics took longer than the young controls to respond on all categories and they had the highest recorded score for all group age bands on HARD, in the 12–14 second range.

Comparing medium-age dyslexics to medium-age controls

Apart from the HN and HARD categories (ns) the medium-age controls were significantly faster than the medium-age dyslexics ($p < 0.05$). The medium-age controls had a mean response time that was 1.39 seconds faster than the dyslexics on HC. On the topographical terrain (Figure 12.13) the medium-age dyslexics had a higher terrain than the medium-age controls.

Comparing old dyslexics with old controls

Group comparisons in the old age band showed that the dyslexics were significantly slower than the controls in all categories ($p < 0.01$) and thus the dyslexic performance in the old age band was relatively weaker than in the medium age band in comparison to the non-dyslexics. The harder the category for the controls (as found on the order of difficulty) the greater the difference in the mean response time between the groups. Thus where the controls took longer to respond the dyslexics took extra long (see Table 12.10 and Figure 12.7). On the topographical terrain (Figure 12.13) the old dyslexics had a higher terrain than the old controls indicating longer mean response times.

Question 2: *Are younger dyslexics slower than older dyslexics?*

The answer to this question is 'yes' and 'no'.

Figure 12.8 shows the mean response time for the three dyslexic age bands. The young age band took particularly longer than the older dyslexics on all addition categories. The old dyslexics were the quickest except on HARD where the medium-age dyslexics were faster. Figure 12.9 illustrates the mean response time by the controls. A different pattern of response is seen between the three age bands. There is consistent improvement (in a descending step formation) on speed of response with increasing age. This trend is also shown on the topographical terrain diagram in Figure 12.13.

Young dyslexics compared to medium-age dyslexics

The young dyslexics took from 3.90 seconds (HARD) to 6.06 seconds (LC) longer than the medium-age dyslexics to respond (mean response times taken), whereas the young controls took between 0.79 seconds (LN) and 1.96 seconds (HARD) longer than the medium-age controls to respond. t-Tests showed that the young dyslexics were slower than the medium-age dyslexics on all categories ($p < 0.001$ and on HARD, $p < 0.05$) whereas the only difference between the two control age bands was on LC ($p < 0.05$), where the medium-age controls were quicker.

Thus the controls showed less difference in response time, between the young and medium age band on each category, than the dyslexics.

Medium-age dyslexics compared to old dyslexics

The difference between these two age bands was less than 1 second across all categories. The medium-age dyslexics were quicker than the old dyslexics on HARD. The old controls were quicker than the medium-age controls on all categories from between 0.97 seconds (LC) to 1.89 seconds (HARD). t-Tests showed no significant difference between the medium-age and old dyslexics on any category, whereas the old controls were significantly faster than the medium-age controls on all categories ($p < 0.05$) except on HARD (ns).

Young dyslexics compared to old dyslexics

The old dyslexics were significantly faster than the young dyslexics on all categories ($p < 0.001$) except HARD (ns) whereas the significance was present in all categories for the controls ($p < 0.001$).

Question 3: *Are there any special number combinations, which are more likely than others to take more time?*

In order to answer this question, different addition categories were compared with each other. The main findings are as follows:

LN compared to LC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LN and also LC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band ($p < 0.001$) on both conditions. When comparing the mean response time across the conditions, responses were faster on LN than on LC for all groups except medium-age controls (young dyslexics and old controls ($p < 0.001$), old dyslexics ($p < 0.01$), young controls and medium-age dyslexics ($p < 0.05$)).

HN compared to HC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on HN and also HC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band ($p < 0.001$) on both conditions. When comparing the mean response times across the conditions all group age bands were faster on HN than HC ($p < 0.001$).

LN compared to HN

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LN and also HN ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band ($p < 0.001$) on both conditions. There was no significant difference between LN and HN for any of the group age bands.

LC compared to HC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LC and also HC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band ($p < 0.001$) on both conditions. When comparing the mean response times across the conditions all group age bands were faster on LC ($p < 0.001$) including the young dyslexics ($p < 0.01$).

HN compared to LC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on HN and also LC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band ($p < 0.001$) on both conditions. When comparing the mean response times across the conditions, the young dyslexics ($p < 0.01$), medium-age dyslexics, old dyslexics and old controls were faster on HN ($p < 0.05$).

LN compared to HARD

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LN and also HARD ($p < 0.001$ and $p < 0.01$ respectively). The performance of the age bands was different ($p < 0.001$) in both conditions and there was an intercept between group and age band on LN ($p < 0.001$) but not on HARD (ns). When comparing the mean response times across the conditions, all group age bands responded quicker on LN ($p < 0.001$) including the young dyslexics ($p < 0.05$).

LN/HN compared to LC/HC

This combination of categories was designed to compare addition questions that crossed the ten barrier with those that did not. Tests of between-subjects effects showed that there was a significant difference ($p < 0.001$) between the groups, age bands and the intercept of group and age band on both conditions with the controls being the quicker. When comparing the mean response times across the conditions, all group age bands responded faster on LN/HN ($p < 0.001$) and thus were significantly quicker to respond to questions that did not cross the ten barrier.

LN/LC compared to HN/HC

This combination of categories was designed to compare addition questions with low addends and high addends. Tests of between-subjects effects showed that there was a significant difference between the groups ($p < 0.001$) in both conditions, where the controls were quicker than the dyslexics, age bands (low addends ($p < 0.001$), high addends ($p < 0.01$)) and a significant intercept of group and age band on low addends ($p < 0.01$) but not on high addends (ns). When comparing the mean response times across the conditions, all group age bands responded quicker on LN/LC ($p < 0.001$) including the young dyslexics ($p < 0.01$). Thus group age bands were significantly faster in responding to questions with low addends.

Comparing low/high addends (LH) with not crossing/crossing (NC) the ten barrier

Figure 12.14 shows the difference in mean response times on LH and NC by group and age band. The controls were significantly faster than the dyslexics on the NC condition ($p < 0.001$), but there was no significant difference between the groups on the LH condition. Comparing the groups in each age band, the young controls were faster than the young dyslexics on the NC condition ($p < 0.01$) but not in the LH condition (ns). A ratio of greater difficulty for the young dyslexics than the young controls was found to be 1 (LH) : 5.25 (NC). Thus the NC condition had a greater effect on the young dyslexics than the LH condition.

No significant difference was found between the groups on these two conditions in the medium age band, but the ratio of difficulty (1 (LH) : 2.23 (NC)) showed that the NC condition had a larger effect on the medium-age dyslexic performance when their mean response times were compared with the medium-age controls.

On the old age band the controls were quicker than the dyslexics on LH ($p < 0.05$) and on NC ($p < 0.05$). A ratio of greater difficulty for the old dyslexics than the old controls was found to be 1 (LH) : 1.5 (NC). Thus the NC condition had a bigger effect on the old dyslexics.

Therefore the dyslexics are significantly slower than the non-dyslexics on questions that involve crossing the ten barrier. This factor has more of an effect on dyslexics when compared to non-dyslexics than whether the addend is high or low.

CHAPTER 13

Speed of Subtraction

13.1 Aims of This Chapter

13.2 Overall Comparisons

13.3 Tasks Within Subtraction

13.4 Differences Between the Dyslexics and Non-dyslexics on Subtraction

13.5 Comparing Age Bands Within the Separate Groups

13.6 Order of Difficulty

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13.8 Special Number Combinations in Subtraction

13.9 Chapter Summary – Questions Answered

13.1 Aims of This chapter

This chapter is designed to address the following three questions.

When performing the mathematical operation of subtraction:

(1) Do dyslexics need more time than non-dyslexics?

(2) Are younger dyslexics slower than older dyslexics?

(3) Are there any special number combinations that are more likely than others to take more time?

13.2 Overall Comparisons

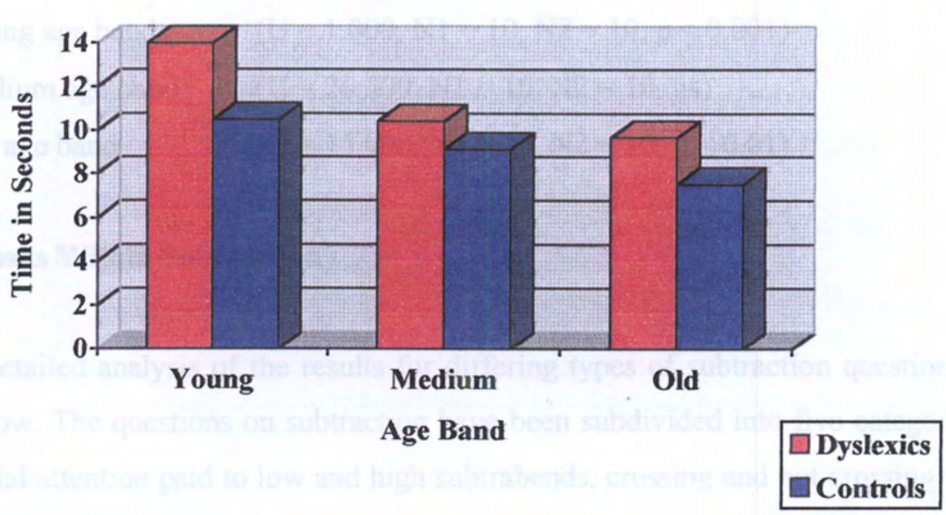
All the subtraction response times were combined and a comparison was drawn up between the two experimental groups and the three age bands.

The mean, standard deviation and median response times (in seconds) for groups and age bands are given in Table 13.1. The mean response time is illustrated in Figure 13.1.

Table 13.1 Mean, standard deviation and median response times (in seconds) by group and age on subtraction

Groups	*Age bands*	*Mean*	*Standard deviation*	*Median*
Dyslexics	Young	13.98	2.55	13.86
	Medium	10.40	2.13	9.87
	Old	9.66	1.55	9.41
Controls	Young	10.47	2.27	10.74
	Medium	9.12	2.19	9.21
	Old	7.51	1.23	7.69

Figure 13.1 Mean response time by group and age on subtraction



Analysis of variance shows the following overall results:

The main effect for age on response time was significant ($F(2,54) = 16.617$, $p < 0.001$).

The older participants took significantly less time to respond than the younger ones.

The main effect of group (dyslexics, controls) was significant ($F(1,54) = 19.305$, $p < 0.001$).

There was no significant interaction between group and age ($F(2,54) = 1.533$, ns). The dyslexics did not perform differentially worse than the controls.

Analysis of variance tables are presented in Appendix F8.

Post hoc testing using Tamhane gave a significant difference between the young and medium age band ($p < 0.05$) and the young and old age band ($p < 0.001$) but not the medium and old age band (ns).

In order to compare the dyslexics with non-dyslexics in each age band, a Mann-Whitney Test was conducted. This showed the following:

- Young age band ($U = 1.000$, $N1 = 10$, $N2 = 10$, $p < 0.001$)
- Medium age band ($U = 26.000$, $N1 = 10$, $N2 = 10$, ns)
- Old age band ($U = 15.000$, $N1 = 10$, $N2 = 10$, $p < 0.01$)

13.3 Tasks Within Subtraction

A more detailed analysis of the results for differing types of subtraction question is given below. The questions on subtraction have been subdivided into five categories with special attention paid to low and high subtrahends, crossing and not crossing the ten barrier and 'hard' questions.

The subtraction categories have been labelled as follows:

- LN = subtraction questions with low subtrahends which do not involve crossing the ten barrier.
- HN = subtraction questions with high subtrahends which do not involve crossing the ten barrier.
- LC = subtraction questions with low subtrahends which involve crossing the ten barrier.
- HC = subtraction questions with high subtrahends which involve crossing the ten barrier.
- HARD = 'hard' questions involving subtraction with two digits and potential 'borrowing' on both.

An analysis of variance was carried out on group and age band performance on each of the subtraction categories. The results are displayed in Table 13.2. Post hoc tests comparing groups and age bands are presented in Tables 13.3 and 13.4 respectively.

Table 13.2 Analysis of variance results (between-subjects effects) showing significant differences in mean response times between groups, age bands and the intercept of groups and age bands

Category	*Groups*	*Age bands*	*Group and age band*
LN	26.668***	27.880***	4.753*
HN	19.193***	23.627***	5.906**
LC	15.064***	16.917***	3.470*
HC	16.547***	14.647***	0.486 (ns)
HARD	4.644*	1.225 (ns)	0.634 (ns)
	F (1,54)	F (2,54)	F (2,54)

Significance levels key for Tables 13.2, 13.3 and 13.4:

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

There was a significant difference between the two groups on all subtraction categories. The difference between the age bands was also significant on all categories except HARD. The intercept of group and age was significant on LN, HN and LC but not on HC and HARD.

Table 13.3 Post hoc tests (Mann-Whitney U) between groups

Addition category	*Group comparisons within each age band*		
	Young	*Medium-age*	*Old*
LN	8.000***	25.000 (ns)	12.000**
HN	7.000***	35.000 (ns)	12.000**
LC	10.000**	36.000 (ns)	23.000*
HC	21.000*	33.000 (ns)	16.000**
HARD	46.000 (ns)	38.000 (ns)	18.000*

Table 13.4 Post hoc tests (multiple comparisons – Tamhane) between age bands

Subtraction category	*Age band comparisons*		
	Y/M	*Y/O*	*M/O*
LN	**	***	ns
HN	**	***	ns
LC	*	***	ns
HC	*	***	ns
HARD	ns	ns	ns

Key: Y (young age band), M (medium age band), O (old age band).

The mean response times for groups on subtraction categories are given for each age band in turn. These are presented in Tables 13.5, 13.6 and 13.7 and illustrated in Figures 13.2, 13.3 and 13.4.

Table 13.5 Mean response times for each group and subtraction category in the young age band (standard deviation given in brackets)

Subtraction Category	*Young dyslexics*		*Young controls*	
LN	10.64	(2.94)	5.99	(2.25)
HN	10.20	(3.25)	5.61	(1.81)
LC	10.35	(3.05)	6.33	(1.66)
HC	12.38	(3.16)	8.96	(2.90)
HARD	11.88	(4.17)	11.23	(4.84)

Figure 13.2 Mean response times for each group and subtraction category in the young age band

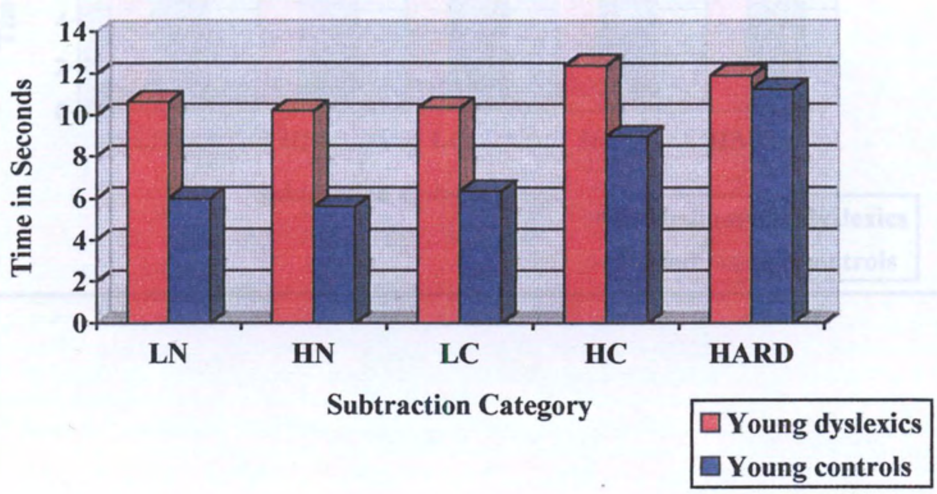


Table 13.6 Mean response times for each group and subtraction category in the medium age band (standard deviation given in brackets)

Subtraction category	*Medium-age dyslexics*		*Medium-age controls*	
LN	5.55	(1.36)	4.44	(1.88)
HN	5.07	(1.21)	4.59	(2.36)
LC	6.30	(1.95)	5.53	(2.36)
HC	8.65	(2.87)	6.80	(2.10)
HARD	12.24	(4.02)	10.08	(2.87)

Figure 13.3 Mean response times for each group and subtraction category in the medium age band

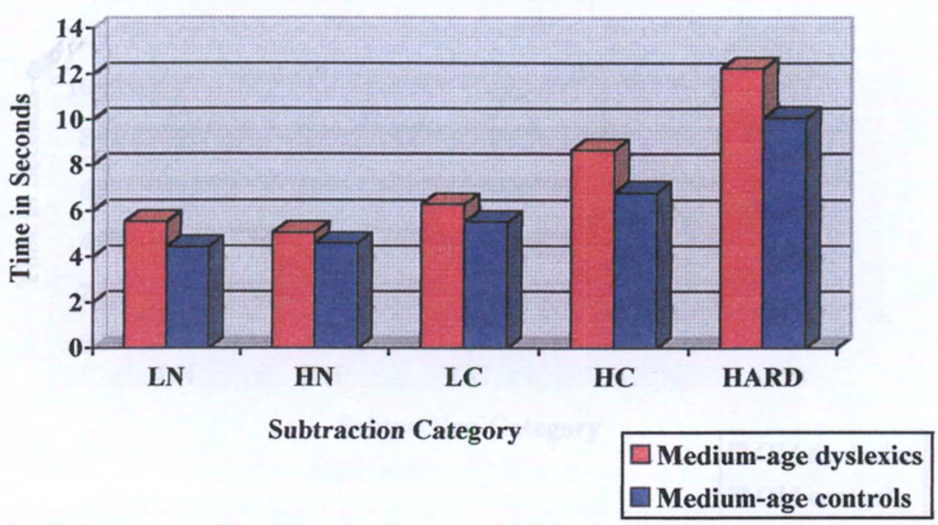
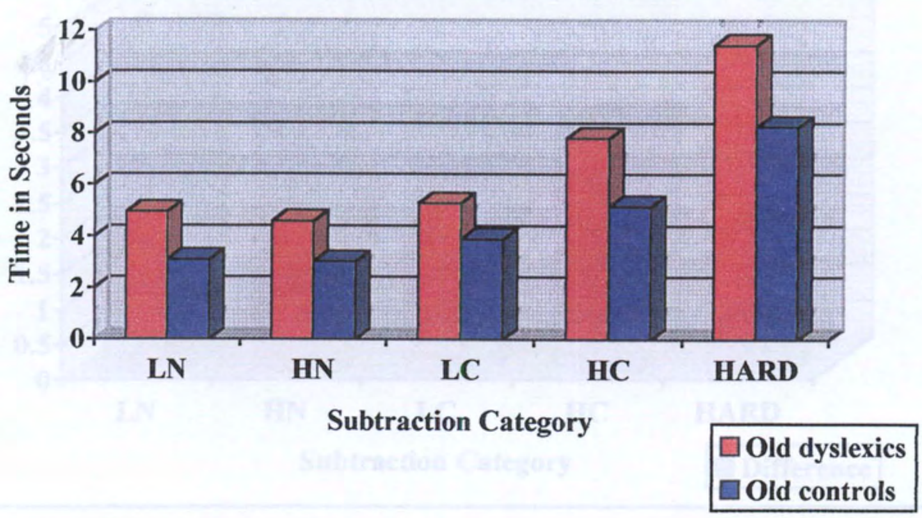


Table 13.7 Mean response times for each group and subtraction category in the old age band (standard deviation given in brackets)

Subtraction category	*Old dyslexics*		*Old controls*	
LN	4.96	(1.38)	3.08	(0.88)
HN	4.60	(1.31)	3.01	(0.72)
LC	5.30	(1.60)	3.89	(1.27)
HC	7.81	(2.16)	5.18	(1.43)
HARD	11.45	(2.40)	8.26	(2.55)

Figure 13.4 Mean response times for each group and subtraction category in the old age band



13.4 Differences Between the Dyslexics and Non-dyslexics on Subtraction

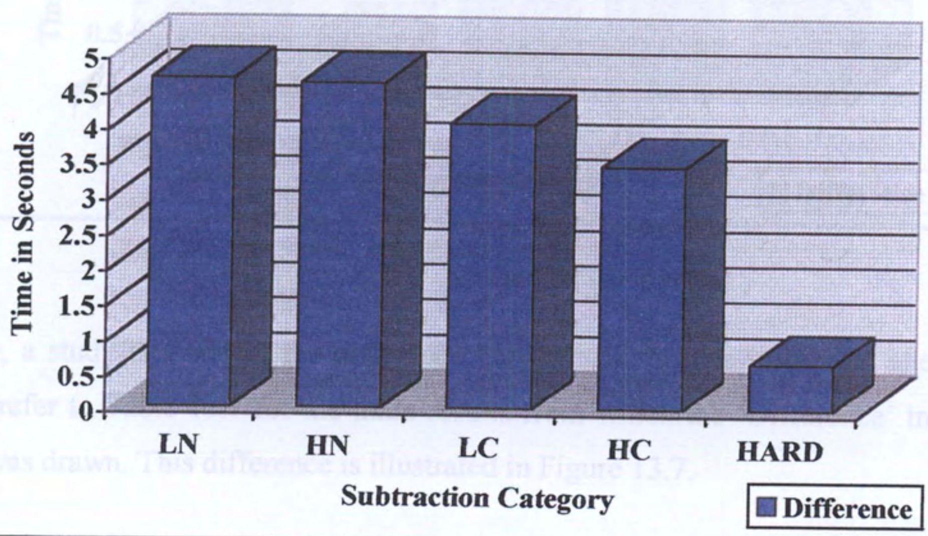
The information in this section does not display new data but draws on the results found in section 13.3. This section enables the reader to analyse the differences found in the mean times between the two experimental groups.

Firstly, a study was made of the difference between the groups in the young age band. See Table 13.5 for the main results from which the 'Difference' in Table 13.8 was drawn. This difference is illustrated in Figure 13.5.

Table 13.8 Differences in mean response times (in seconds) between the dyslexic and control groups in the young age band

	Subtraction category				
	LN	*HN*	*LC*	*HC*	*HARD*
Difference	4.65	4.59	4.02	3.42	0.65

Figure 13.5 Differences in mean response times between the groups in the young age band

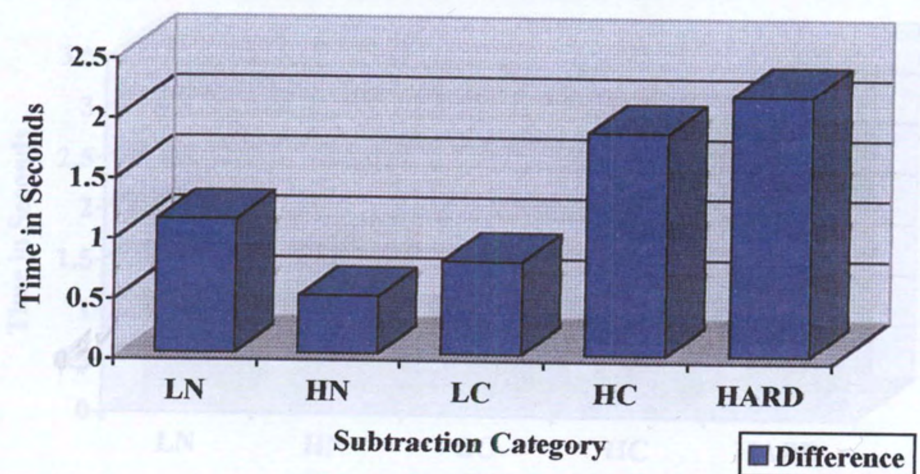


Secondly, a study was made of the difference between the groups in the medium age band. See Table 13.6 for the main results from which the 'Difference' in Table 13.9 was drawn. This difference is illustrated in Figure 13.6.

Table 13.9 Differences in mean response times (in seconds) between the dyslexic and control groups in the medium age band

	Subtraction category				
	LN	*HN*	*LC*	*HC*	*HARD*
Difference	1.11	0.48	0.77	1.85	2.16

Figure 13.6 Differences in mean response times between the groups in the medium age band

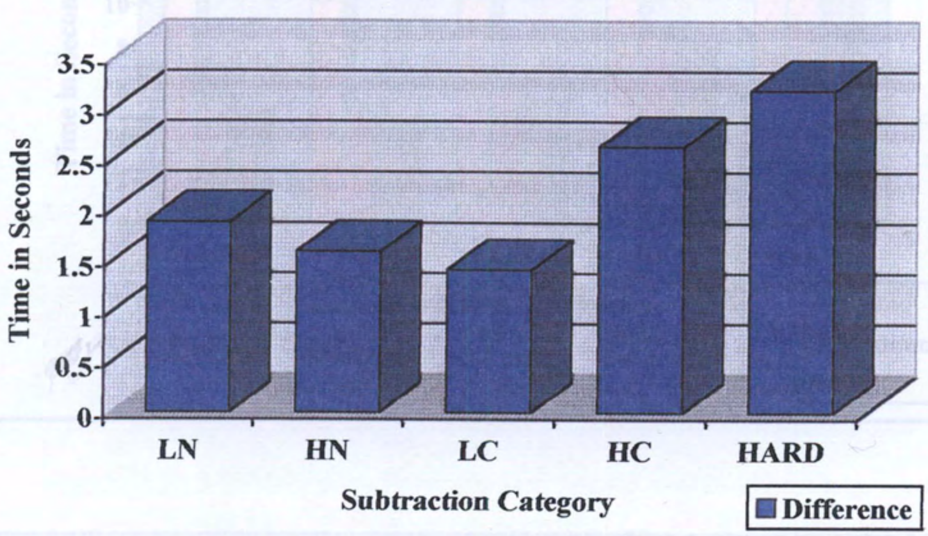


Thirdly, a study is made of the difference between the groups in the old age band. Please refer to Table 13.7 for the main results from which the 'Difference' in Table 13.10 was drawn. This difference is illustrated in Figure 13.7.

Table 13.10 Differences in mean response times (in seconds) between the dyslexic and control groups in the old age band

	Subtraction category				
	LN	*HN*	*LC*	*HC*	*HARD*
Difference	1.88	1.59	1.41	2.63	3.19

Figure 13.7 Differences in mean response times between the groups in the old age band



13.5 Comparing Age Bands Within the Separate Groups

Is the difference between the age bands the same for both groups or are the dyslexics different? Does the speed of response to subtraction questions improve with age for both groups?

The information in this section does not display new data but draws on the results found in section 13.3. This section enables the reader to compare age band performance within the separate groups.

The mean response time on each category is recorded in Figure 13.8 for each of the dyslexic age bands. Figure 13.9 gives the results for each of the control age bands. Both figures have been placed together for ease of comparison between the performance of the dyslexic and non-dyslexic groups.

Figure 13.8 Mean response time (seconds) for the three dyslexic age bands on all categories.

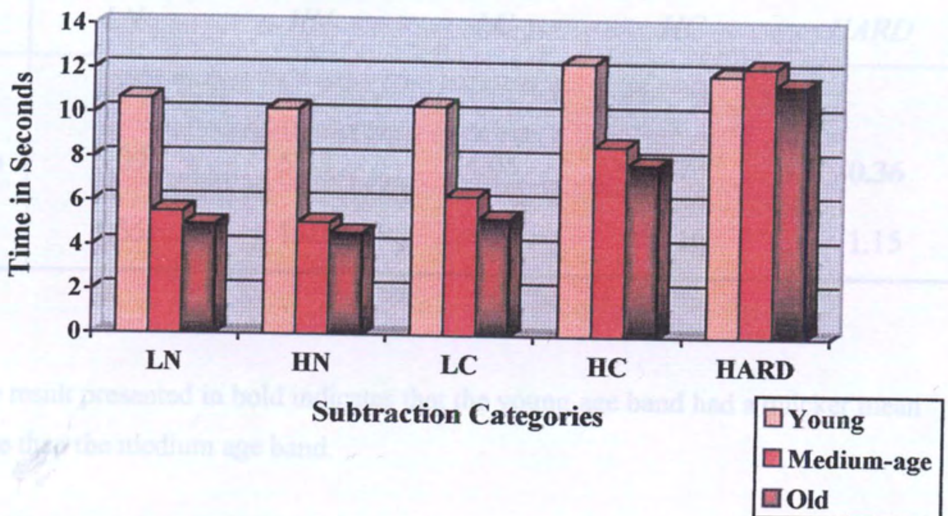
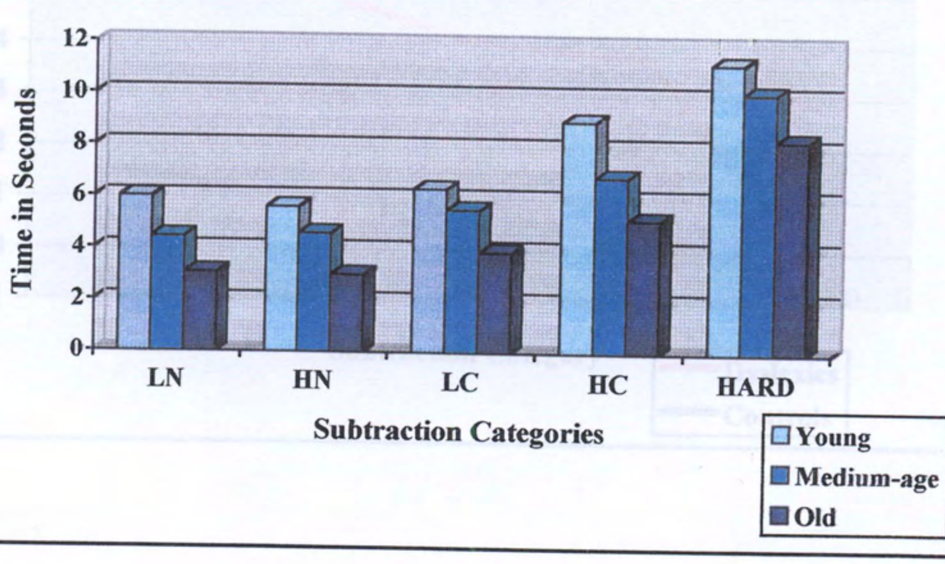


Figure 13.9 Mean response time (seconds) for the three control age bands on all categories.



13.5.1 Comparison of the Young and Medium Age Bands on Subtraction Tasks

The results are presented in Table 13.11 and Figure 13.10.

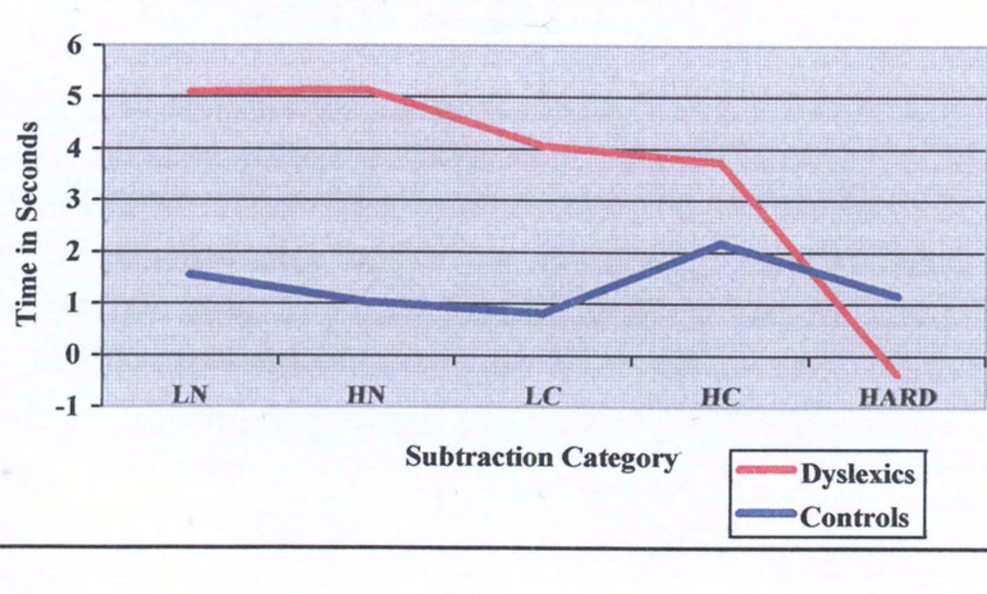
Table 13.11 Differences between the young and medium age band mean response times (in seconds) for each group

Groups	*Subtraction category*				
	LN	*HN*	*LC*	*HC*	*HARD*
Dyslexics	5.09	5.13	4.05	3.73	**–0.36**
Controls	1.55	1.02	0.8	2.16	1.15

<u>Note.</u>

The negative result presented in bold indicates that the young age band had a quicker mean response time than the medium age band.

Figure 13.10 Differences between the young and medium age band mean response times (in seconds) for each group



t-Tests comparing the young and medium age bands in each group show:

Dyslexic group:

- LN (t = 4.964, df = 18, $p < 0.001$)
- HN (t = 4.684, df = 18, $p < 0.001$)
- LC (t = 3.538, df = 18, $p < 0.01$)
- HC (t = 2.763, df = 18, $p < 0.05$)
- HARD (t = 0.199, df = 18, ns)

Control group:

- LN (t = 1.675, df = 18, ns)
- HN (t = 1.080, df = 18, ns)
- LC (t = 0.877, df = 18, ns)
- HC (t = 1.910, df = 18, ns)
- HARD (t = 0.645, df = 18, ns)

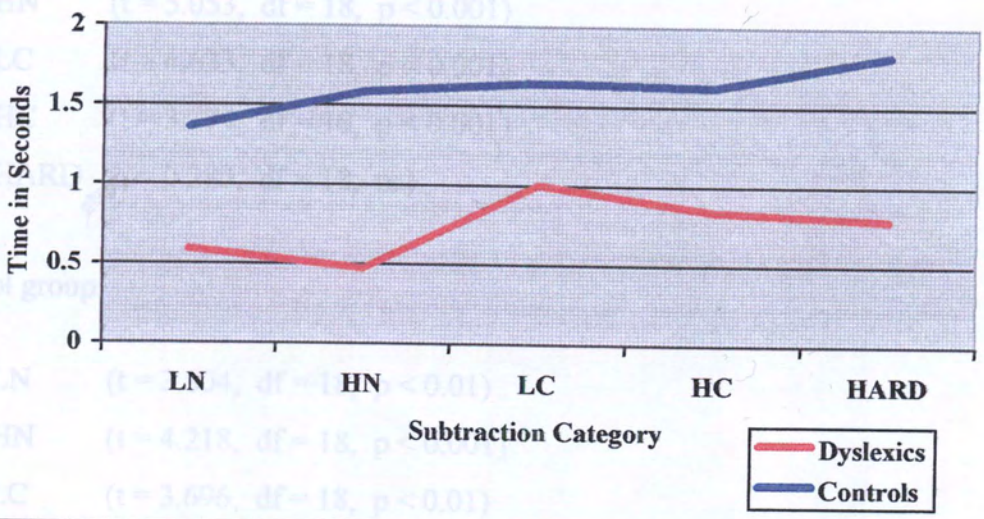
13.5.2 Comparison of the Medium and Old Age Bands on Subtraction Tasks

The results are presented in Table 13.12 and Figure 13.11.

Table 13.12 Differences between the medium and old age band mean response times (in seconds) for each group

Groups	*Subtraction category*				
	LN	*HN*	*LC*	*HC*	*HARD*
Dyslexics	0.59	0.47	1	0.84	0.79
Controls	1.36	1.58	1.64	1.62	1.82

Figure 13.11 Differences between the medium and old age band mean response times (in seconds) for each group



t-Tests comparing the medium and old age bands in each group show:

Dyslexic group:

- LN (t = 0.955, df = 18, ns)
- HN (t = 0.821, df = 18, ns)
- LC (t = 1.253, df = 18, ns)
- HC (t = 0.739, df = 18, ns)
- HARD (t = 0.533, df = 18, ns)

Control group:

- LN ($t = 2.063$, $df = 18$, ns)
- HN ($t = 2.024$, $df = 18$, ns)
- LC ($t = 1.939$, $df = 18$, ns)
- HC ($t = 2.017$, $df = 18$, ns)
- HARD ($t = 1.501$, $df = 18$, ns)

t-Tests comparing the young and old age bands in each group show:

Dyslexic group:

- LN ($t = 5.523$, $df = 18$, $p < 0.001$)
- HN ($t = 5.053$, $df = 18$, $p < 0.001$)
- LC ($t = 4.633$, $df = 18$, $p < 0.001$)
- HC ($t = 3.774$, $df = 18$, $p < 0.001$)
- HARD ($t = 0.280$, $df = 18$, ns)

Control group:

- LN ($t = 3.804$, $df = 18$, $p < 0.01$)
- HN ($t = 4.218$, $df = 18$, $p < 0.001$)
- LC ($t = 3.696$, $df = 18$, $p < 0.01$)
- HC ($t = 3.705$, $df = 18$, $p < 0.01$)
- HARD ($t = 1.718$, $df = 18$, ns)

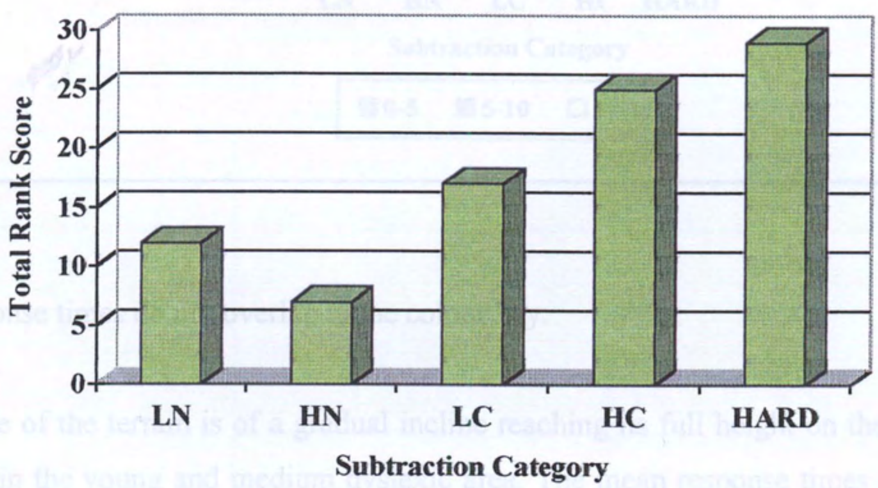
13.6 Order of Difficulty

The results displayed in Tables 13.5, 13.6 and 13.7 show the mean response times for groups and age bands on each subtraction category. Table 13.13 shows the rank order of difficulty of the subtraction categories for each group and age band found from these Tables. The ranks have been totalled and the 'overall rank' found from these. The results are illustrated in Figure 13.12.

Table 13.13 Order of difficulty for the five subtraction categories

Subtraction category	*Dyslexics*			*Controls*			*Total rank score*	*Overall rank*
	Age band							
	Young	*Medium*	*Old*	*Young*	*Medium*	*Old*		
LN	3	2	2	2	1	2	12	2
HN	1	1	1	1	2	1	7	1
LC	2	3	3	3	3	3	17	3
HC	5	4	4	4	4	4	25	4
HARD	4	5	5	5	5	5	29	5

Figure 13.12 Subtraction category total rank scores for all groups and age bands combined



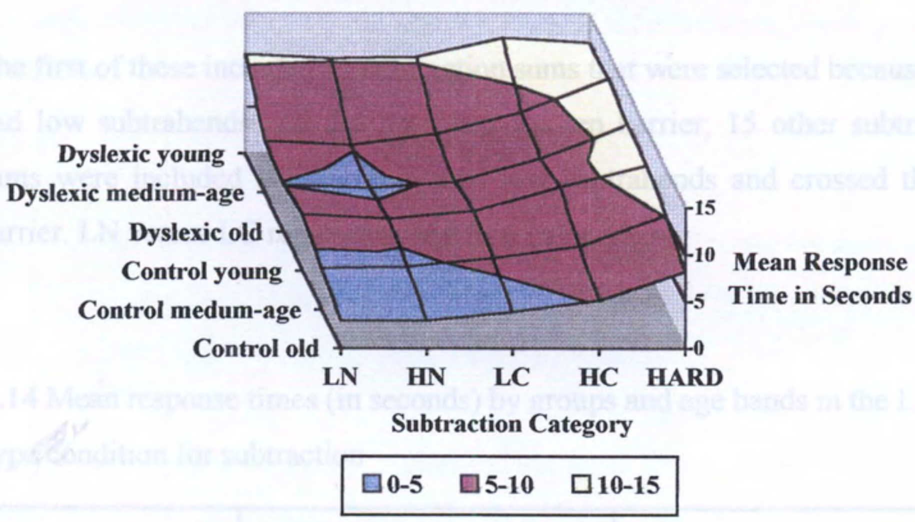
Using Spearman's non-parametric correlation, rho = 0.76 ($p < 0.001$) showing that the order for the groups and age bands was significantly the same.

If the criterion is speed of performing subtraction, the standard order of difficulty for the subtraction categories was HN, LN, LC, HC and HARD.

13.7 Topographical Terrain

The topographical terrain displayed in Figure 13.13 is composed of the mean response times found on each category for the dyslexics and non-dyslexics in the three age bands.

Figure 13.13 Topographical terrain for the mean response time for group and age band on subtraction categories



The response times do not overlap in the colour key.

The shape of the terrain is of a gradual incline reaching its full height on the HARD category in the young and medium dyslexic area. The mean response times are least for the old controls on LN, HN and LC.

13.8 Special Number Combinations in Subtraction

This section is designed specifically to answer question 3 posed at the start of the chapter. Are there any special number combinations for subtraction that are more likely than others to take more time?

Which subtraction combinations do the dyslexics find the hardest to respond to quickly? In the case of subtraction facts that involve extra algorithms (steps), are dyslexics weaker at responding quickly when compared to the controls?

Subtraction has been divided into questions with high/low subtrahends, questions that do and do not cross the ten barrier and finally questions that have a combination of high subtrahends and the need to cross the ten barrier on both the units and tens.

Several groupings of 30 subtraction sums were chosen to test this prediction.

(1) The first of these included 15 subtraction sums that were selected because they had low subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had low subtrahends and crossed the ten barrier. LN versus LC represents this. See Table 13.14.

Table 13.14 Mean response times (in seconds) by groups and age bands in the LN and LC type condition for subtraction

Groups and age bands	*LN condition*	*LC condition*
Young age band		
Dyslexics	10.64	10.35
Controls	5.99	6.33
Medium age band		
Dyslexics	5.55	6.30
Controls	4.44	5.53
Old age band		
Dyslexics	4.96	5.30
Controls	3.08	3.89

t-Test results on paired samples LN and LC for groups and age bands are as follows:

- Young controls $t = 0.802$, $df = 9$, ns
- Young dyslexics $t = 1.056$, $df = 9$, ns
- Medium-age controls $t = 4.629$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 1.707$, $df = 9$, ns
- Old controls $t = 2.560$, $df = 9$, $p < 0.05$
- Old dyslexics $t = 0.972$, $df = 9$, ns

Tests of between-subjects effects on LN gave a significant difference between groups ($F(1,54) = 26.668$, $p < 0.001$) and age bands ($F(2,54) = 27.880$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 4.753$, $p < 0.05$).

Tests of between-subjects effects on LC gave a significant difference between groups ($F(1,54) = 15.064$, $p < 0.001$) and age bands ($F(2,54) = 16.917$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 3.470$, $p < 0.05$).

(2) The second of these included 15 subtraction sums that were selected because they had high subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had high subtrahends and crossed the ten barrier. HN versus HC represents this. See Table 13.15.

Table 13.15 Mean response times (in seconds) by groups and age bands in the HN and HC type condition for subtraction

Groups and age bands	*HN condition*	*HC condition*
Young age band		
Dyslexics	10.20	12.38
Controls	5.61	8.96
Medium age band		
Dyslexics	5.07	8.65
Controls	4.59	6.80
Old age band		
Dyslexics	4.60	7.81
Controls	3.01	5.18

t-Test results on paired samples HN and HC for groups and age bands are as follows:

- Young controls $t = 6.278$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 3.028$, $df = 9$, $p < 0.05$
- Medium-age controls $t = 5.449$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 5.090$, $df = 9$, $p < 0.001$
- Old controls $t = 7.278$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 6.831$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on HN give a significant difference between groups ($F (1,54) = 19.193$, $p < 0.001$) and age bands ($F (2,54) = 23.627$, $p < 0.001$) and the intercept of group and age band ($F (2,54) = 5.906$, $p < 0.01$).

Tests of between-subjects effects on HC show that there is a significant difference between groups ($F (1,54) = 16.547$, $p < 0.001$) and age bands ($F (2,54) = 14.647$,

$p < 0.001$) but no significant difference between the intercept of group and age band ($F(2,54) = 0.486$, ns).

(3) The third of these included 15 subtraction sums that were selected because they had low subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had high subtrahends and did not cross the ten barrier. LN versus HN represents this. See Table 13.16.

Table 13.16 Mean response times (in seconds) by groups and age bands in the LN and HN type condition for subtraction

Groups and age bands	*LN condition*	*HN condition*
Young age band		
Dyslexics	10.64	10.20
Controls	5.99	5.61
Medium age band		
Dyslexics	5.55	5.07
Controls	4.44	4.59
Old age band		
Dyslexics	4.96	4.60
Controls	3.08	3.01

t-Test results on paired samples LN and HN for groups and age bands are as follows:

- Young controls $t = 1.267$, $df = 9$, ns
- Young dyslexics $t = 0.969$, $df = 9$, ns
- Medium-age controls $t = 0.671$, $df = 9$, ns
- Medium-age dyslexics $t = 1.680$, $df = 9$, ns
- Old controls $t = 0.568$, $df = 9$, ns
- Old dyslexics $t = 1.462$, $df = 9$, ns

Tests of between-subjects effects on LN give a significant difference between groups ($F(1,54) = 26.668$, $p < 0.001$) and age bands ($F(2,54) = 27.880$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 4.753$, $p < 0.05$).

Tests of between-subjects effects on HN give a significant difference between groups ($F(1,54) = 19.193$, $p < 0.001$) and age bands ($F(2,54) = 23.627$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 5.906$, $p < 0.01$).

(4) The fourth of these included 15 subtraction sums that were selected because they had low subtrahends and crossed the ten barrier; 15 other subtraction sums were included because they had high subtrahends and crossed the ten barrier. LC versus HC represents this. See Table 13.17.

Table 13.17 Mean response times (in seconds) by groups and age bands in the LC and HC type condition for subtraction

Groups and age bands	*LC condition*	*HC condition*
Young age band		
Dyslexics	10.35	12.38
Controls	6.33	8.96
Medium age band		
Dyslexics	6.30	8.65
Controls	5.53	6.80
Old age band		
Dyslexics	5.30	7.81
Controls	3.89	5.18

t-Test results on paired samples LC and HC for groups and age bands are as follows:

- Young controls $t = 5.078$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 3.793$, $df = 9$, $p < 0.01$
- Medium-age controls $t = 4.125$, $df = 9$, $p < 0.01$
- Medium-age dyslexics $t = 6.559$, $df = 9$, $p < 0.001$
- Old controls $t = 3.723$, $df = 9$, $p < 0.01$
- Old dyslexics $t = 6.626$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LC gave a significant difference between groups ($F\ (1,54) = 15.064$, $p < 0.001$) and age bands ($F\ (2,54) = 16.917$, $p < 0.001$) and the intercept of group and age band ($F\ (2,54) = 3.470$, $p < 0.05$).

Tests of between-subjects effects on HC show that there is a significant difference between groups ($F\ (1,54) = 16.547$, $p < 0.001$) and age bands ($F\ (2,54) = 14.647$, $p < 0.001$) but no significant difference between the intercept of group and age band ($F\ (2,54) = 0.486$, ns).

(5) The fifth of these included 15 subtraction sums that were selected because they had high subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had low subtrahends and crossed the ten barrier. HN versus LC represents this. See Table 13.18.

Table 13.18 Mean response times (in seconds) by groups and age bands in the HN and LC type condition for subtraction

Groups and age bands	*HN condition*	*LC condition*
Young age band		
Dyslexics	10.20	10.35
Controls	5.61	6.33
Medium age band		
Dyslexics	5.07	6.30
Controls	4.59	5.53
Old age band		
Dyslexics	4.60	5.30
Controls	3.01	3.89

t-Test results on paired samples HN and LC for groups and age bands are as follows:

- Young controls $t = 2.359$, $df = 9$, $p < 0.05$
- Young dyslexics $t = 0.281$, $df = 9$, ns
- Medium-age controls $t = 3.918$, $df = 9$, $p < 0.01$
- Medium-age dyslexics $t = 3.057$, $df = 9$, $p < 0.05$
- Old controls $t = 2.970$, $df = 9$, $p < 0.05$
- Old dyslexics $t = 2.451$, $df = 9$, $p < 0.05$

Tests of between-subjects effects on HN give a significant difference between groups ($F(1,54) = 19.193$, $p < 0.001$) and age bands ($F(2,54) = 23.627$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 5.906$, $p < 0.01$).

Tests of between-subjects effects on LC gave a significant difference between groups ($F(1,54) = 15.064$, $p < 0.001$) and age bands ($F(2,54) = 16.917$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 3.470$, $p < 0.05$).

(6) The sixth of these included 15 subtraction sums that were selected because they had low subtrahends and did not cross the ten barrier; 15 other subtraction sums were included because they had high subtrahends, a two-digit number subtracted from a two-digit number and crossed the ten barrier. This is represented by LN versus HARD. See Table 13.19.

Table 13.19 Mean response times (in seconds) by groups and age bands in the LN and HARD type condition for subtraction

Groups and age bands	*LN condition*	*HARD condition*
Young age band		
Dyslexics	10.64	11.88
Controls	5.99	11.23
Medium age band		
Dyslexics	5.55	12.24
Controls	4.44	10.08
Old age band		
Dyslexics	4.96	11.45
Controls	3.08	8.26

t-Test results on paired samples LN and HARD for groups and age bands are as follows:

- Young controls $t = 3.765$, $df = 9$, $p < 0.01$
- Young dyslexics $t = 0.782$, $df = 9$, ns
- Medium-age controls $t = 9.049$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 6.897$, $df = 9$, $p < 0.001$
- Old controls $t = 8.255$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 13.721$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LN give a significant difference between groups ($F(1,54) = 26.668$, $p < 0.001$) and age bands ($F(2,54) = 27.880$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 4.753$, $p < 0.05$).

Tests of between-subjects effects on HARD give a significant difference between groups ($F(1,54) = 4.644$, $p < 0.05$) but not between age bands ($F(2,54) = 1.225$, ns) or the intercept of group and age band ($F(2,54) = 0.634$, ns).

(7) The seventh of these included 30 subtraction sums that were selected because they had low subtrahends, as well as those questions with high subtrahends, which did not cross the ten barrier; 30 other subtraction sums were included because they had low subtrahends, as well as those questions with high subtrahends, which crossed the ten barrier. LN and HN versus LC and HC represent this. See Table 13.20.

Table 13.20 Mean response times (in seconds) by groups and age bands in the LN / HN and LC / HC type condition for subtraction

Groups and age bands	*LN and HN condition*	*LC and HC condition*
Young age band		
Dyslexics	10.42	11.36
Controls	5.8	7.64
Medium age band		
Dyslexics	5.31	7.47
Controls	4.52	6.16
Old age band		
Dyslexics	4.78	6.56
Controls	3.05	4.53

t-Test results on paired samples LN and HN versus LC and HC for groups and age bands are as follows:

- Young controls $t = 6.494$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 1.970$, $df = 9$, ns
- Medium-age controls $t = 7.171$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 4.168$, $df = 9$, $p < 0.01$
- Old controls $t = 6.585$, $df = 9$, $p < 0.001$
- Old dyslexics $t = 5.304$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LN and HN give a significant difference between groups ($F (1,54) = 24.068$, $p < 0.001$) and age bands ($F (2,54) = 27.195$, $p < 0.001$) and the intercept of group and age band ($F (2,54) = 5.632$, $p < 0.01$).

Tests of between-subjects effects on LC and HC show that there is a significant difference between groups ($F (1,54) = 17.136$, $p < 0.001$) and age bands ($F (2,54) = 16.884$, $p < 0.001$) but no significant difference between the intercept of group and age band ($F (2,54) = 1.577$, ns).

(8) The eighth of these included 30 subtraction sums that were selected because they had low subtrahends; 30 other subtraction sums were included because they had high subtrahends. This is represented by LN/LC versus HN/HC. See Table 13.21.

Table 13.21 Mean response times (in seconds) by groups and age bands in the LN/LC and HN/HC type condition for subtraction

Groups and age bands	*LN and LC condition*	*HN and HC condition*
Young age band		
Dyslexics	10.49	11.29
Controls	6.16	7.28
Medium age band		
Dyslexics	5.92	6.86
Controls	4.98	5.70
Old age band		
Dyslexics	5.13	6.21
Controls	3.48	4.09

t-Test results on paired samples LN and LC versus HN and HC for groups and age bands are as follows:

- Young controls $t = 6.155$, $df = 9$, $p < 0.001$
- Young dyslexics $t = 1.903$, $df = 9$, ns
- Medium-age controls $t = 5.497$, $df = 9$, $p < 0.001$
- Medium-age dyslexics $t = 5.313$, $df = 9$, $p < 0.001$
- Old controls $t = 3.824$, $df = 9$, $p < 0.01$
- Old dyslexics $t = 5.238$, $df = 9$, $p < 0.001$

Tests of between-subjects effects on LN/LC give a significant difference between groups ($F(1,54) = 21.847$, $p < 0.001$) and age bands ($F(2,54) = 23.481$, $p < 0.001$) and the intercept of group and age band ($F(2,54) = 4.386$, $p < 0.05$).

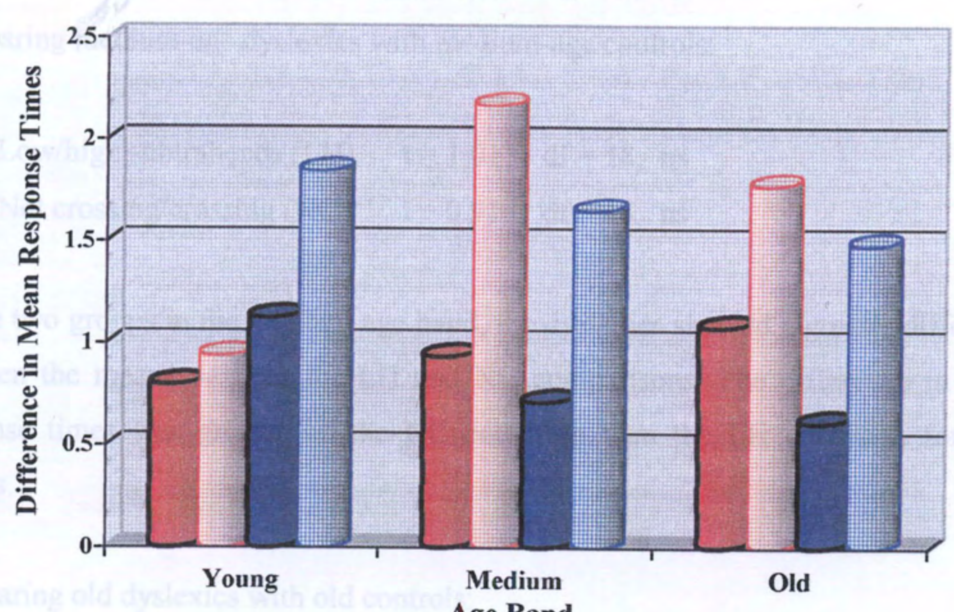
Tests of between-subjects effects on HN/HC show that there is a significant difference between groups ($F(1,54) = 20.396$, $p < 0.001$) and age bands ($F(2,54) = 21.123$, p < 0.001) but no significant difference between the intercept of group and age band (F (2,54) = 2.419, ns).

13.8.1 Comparing Low/High Subtrahends with Not Crossing/Crossing the Ten Barrier

Which number combination has more effect – the low/high subtrahends, or not crossing/crossing the ten barrier? Is there a difference between the groups and if so, in which age bands?

The mean response times for both low and high subtrahends (LH) were compared for all group age bands and the difference found. The same was done for not crossing and crossing (NC) mean response times. The results are displayed in Figure 13.14.

Figure 13.14 Difference in mean response times on LH and NC by group and age band.



A comparison of *all* controls with *all* dyslexics (ages combined) gave the following t-Test results:

- Low/high subtrahends $t = 0.639$, $df = 58$, ns
- Not crossing/crossing $t = 0.099$, $df = 58$, ns

Comparing young dyslexics with young controls:

- Low/high subtrahends (LH) $t = 0.712$, $df = 18$, ns
- Not crossing/crossing (NC) $t = 1.624$, $df = 18$, ns

Of the two groups in the young age band, the controls showed a greater difference between the means on both the LH and NC comparisons. This was due to a floor effect whereby the young dyslexics performed so poorly on both that the difference was less marked. The difference in mean response times was greater on the NC condition than the LH condition for both groups.

Comparing medium-age dyslexics with medium-age controls:

- Low/high subtrahends (LH) $t = 1.013$, $df = 18$, ns
- Not crossing/crossing (NC) $t = 0.914$, $df = 18$, ns

Of the two groups in the medium age band, the dyslexics showed a greater difference between the means on both the LH and NC comparisons. The difference in mean response times was greater on the NC condition than the LH condition for both groups.

Comparing old dyslexics with old controls:

- Low/high subtrahends (LH) $t = 1.795$, $df = 18$, ns
- Not crossing/crossing (NC) $t = 0.727$, $df = 18$, ns

Of the two groups in the old age band, the dyslexics showed a greater difference between the means on both the LH and NC comparisons. The difference in mean response times was greater on the NC condition than the LH condition for both groups.

Table 13.22 has been calculated by taking the difference in the mean response times for low and high subtrahends, and also not crossing and crossing conditions, and then comparing this difference between the groups. Entries in bold indicate which of the conditions was more quickly answered. A ratio of difficulty of the conditions is presented.

Table 13.22 Percentage difference between the groups when comparing the difference in mean response times between the LH conditions and between the NC conditions

Conditions	*Age band*		
	Young	*Medium*	*Old*
Low/high subtrahends (LH)	<u>71%</u>	31%	77%
Not crossing/ crossing (NC)	<u>51%</u>	32%	20%
Ratio of difficulty	1 : 1.39	1 : 0.97	1 : 3.85

<u>Note.</u>

An <u>underlined</u> entry indicates where the dyslexics had a smaller difference between the means than the controls.

13.9 Chapter Summary – Questions Answered

Question 1: *Do dyslexics need more time than non-dyslexics?*

The answer to this question is 'yes'.

An analysis of variance on the mean response time showed that the controls were significantly quicker than the dyslexics ($p < 0.001$). There was a significant difference between the age bands ($p < 0.001$) but there was no significant interaction between group and age (ns).

Post hoc tests (Tamhane) showed that the medium age band was significantly faster than the young age band ($p < 0.05$), and the old age band was faster than the young age band ($p < 0.001$) but there was no significant difference between the medium and old age bands (ns).

A comparison of the two groups in each age band (Mann-Whitney Test) showed that the controls were faster than the dyslexics in the young ($p < 0.001$) and old age bands ($p < 0.01$) but not in the medium age band (ns).

The order of difficulty of the five subtraction categories was significantly the same for all group age bands (Spearman rho = 0.76, $p < 0.001$). The order of difficulty (from fastest to slowest) was: HN, LN, LC, HC and HARD.

An analysis of variance on the mean response time by group and age band on the five categories showed that the controls were significantly quicker than the dyslexics on all categories ($p < 0.001$) including HARD ($p < 0.05$). There was a significant difference between the age bands on all categories ($p < 0.001$) except HARD (ns), and the intercept of group and age band was significant on HN ($p < 0.01$), LN and LC ($p < 0.05$).

Post hoc tests (Tamhane) on age band comparisons showed that the medium age band was significantly quicker than the young age band on LC and HC ($p < 0.05$), LN and HN ($p < 0.01$) but not on HARD. No significant difference was found between the medium and old age band. The old age band was faster than the young age band on all categories ($p < 0.001$) except HARD (ns).

Young dyslexics compared to young controls

Post hoc tests (Mann-Whitney 'U' tests presented in Table 13.3) between groups showed that the controls were significantly faster than the dyslexics in the young age band on all categories (LN and HN ($p < 0.001$), LC ($p < 0.01$) and HC ($p < 0.05$)) except HARD (ns).

On each subtraction category the young dyslexics had a longer mean response time than the young controls. The standard deviation was also greater except in the case of the HARD category. The least difference between the groups was on the HARD category and the greatest difference was on LN, HN and LC with a recorded time difference of greater than 4 seconds. The category with the quickest response time for both groups was HN.

Medium-age dyslexics compared to medium-age controls

On the Mann-Whitney test there was no significant difference between the medium-age dyslexics and medium-age controls (see Table 13.3).

Despite this the medium-age dyslexics had a longer mean response time than the medium-age controls on all subtraction categories (presented in Table 13.6). The smallest difference between the groups was on HN and the greatest was on the HARD category. The order of response times was the same for both groups except on LN and HN, where the medium-age dyslexics were quicker on HN than LN.

Old dyslexics compared to old controls

The old controls were significantly faster than the old dyslexics on all categories (LN, HN and HC ($p < 0.01$), LC and HARD ($p < 0.05$)).

The old controls responded more quickly on all categories than the old dyslexics but the order of category response times was the same for both dyslexics and controls.

The least difference between the groups was on LC and the greatest difference was on HARD (see Table 13.10 and Figure 13.7). Overall there was greater variability among the dyslexic scores than the control results.

The topographical terrain diagram (Figure 13.13) shows the longer response times for the dyslexics compared to the controls, with the highest terrain produced by the young dyslexics. The old controls have the lowest terrain and therefore the quickest mean response times.

Question 2: *Are younger dyslexics slower than older dyslexics:*

The answer to this question is 'yes'.

Figure 13.8 shows the mean response time for the three dyslexic age bands on all categories. The mean response time for the young dyslexics on LN, HN, LC and HC is approximately double that of the other age bands, particularly on the categories that do not cross the ten barrier.

In all categories the medium-age dyslexics take longer to respond than the old dyslexics. The young dyslexics have a lower mean response time than the medium-age dyslexics on the HARD category.

In contrast Figure 13.9 shows the mean response times for the three control age bands on all categories. The results show a consistent and steady improvement in mean response time with age.

Young dyslexics compared to medium-age dyslexics

t-Tests show that the medium-age dyslexics are significantly quicker than the young dyslexics on LN and HN ($p < 0.001$), LC ($p < 0.01$) and HC ($p < 0.05$) but not on

HARD (ns). There is no significant difference between the young and medium-age controls on any category.

Medium-age dyslexics compared to old dyslexics

t-Tests show that there are no significant differences between the medium-age and old dyslexics and likewise for the medium-age and old controls.

In all cases the old age band have quicker mean response times than the medium age band indicated by positive scores. The dyslexic group has the least difference between the age bands than the control group on all categories.

Young dyslexics compared to old dyslexics

t-Tests show that the old dyslexics are significantly quicker than the young dyslexics in all categories ($p < 0.001$) except HARD (ns). Likewise the old controls are faster than the young controls on HN ($p < 0.001$), LN, LC and HC ($p < 0.01$) but not on HARD (ns).

The topographical terrain diagram (Figure 13.13) shows the steepest incline to be between the young and medium-age dyslexics. This represents the greatest difference in mean response times between within-group age bands.

Question 3: *Are there any special number combinations, which are more likely than others to take more time?*

In order to answer this question, different subtraction categories were compared with each other. The main findings are as follows.

LN compared to LC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LN and also LC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band

($p < 0.05$) on both conditions. When comparing the mean response time across the conditions, responses were significantly faster on LN than on LC for the medium-age controls ($p < 0.001$) and old controls ($p < 0.05$).

HN compared to HC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on HN and also HC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band on HN ($p < 0.01$) but not on the HC condition. When comparing the mean response times across the conditions, all group age bands were faster on HN than HC ($p < 0.001$) including the young dyslexics ($p < 0.05$).

LN compared to HN

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LN and also HN ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band ($p < 0.05$ and $p < 0.01$ respectively) on both conditions. There was no significant difference between LN and HN for any of the group age bands.

LC compared to HC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LC and also HC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band on LC ($p < 0.05$) but not on the HC condition. When comparing the mean response times across the conditions, all group age bands were significantly faster on LC (young controls, medium-age dyslexics and old dyslexics ($p < 0.001$), all other group age bands ($p < 0.01$)).

HN compared to LC

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on HN and also LC ($p < 0.001$). The performance of the age bands was different ($p < 0.001$) and there was an intercept between group and age band ($p < 0.01$ and $p < 0.05$ respectively) on both conditions. When comparing the mean response times across the conditions, the medium-age controls ($p < 0.01$), young controls, medium-age dyslexics, old dyslexics and old controls were faster on HN ($p < 0.05$).

LN compared to HARD

Tests of between-subjects effects showed that the controls were significantly quicker than the dyslexics on LN and also HARD ($p < 0.001$ and $p < 0.05$ respectively). The performance of the age bands was different on LN ($p < 0.001$) but not on HARD. The intercept between group and age band was significant on LN ($p < 0.05$) but not on HARD (ns). When comparing the mean response times across the conditions, all group age bands responded quicker on LN ($p < 0.001$ and $p < 0.01$ for the young controls) except the young dyslexics (ns).

LN/HN compared to LC/HC

This combination of categories was designed to compare subtraction questions that crossed the ten barrier with those that did not. Tests of between-subjects effects on each condition showed that there was a significant difference between the groups ($p < 0.001$), in favour of the controls, and age bands ($p < 0.001$). The intercept between group and age band was significant for the LN/HN condition ($p < 0.01$) but not for the LC/HC condition. When comparing the mean response times across the conditions, all group age bands responded faster on LN/HN ($p < 0.001$ and $p < 0.01$ for the medium-age dyslexics) except the young dyslexics (ns).

LN/LC compared to HN/HC

This combination of categories was designed to compare subtraction questions with low subtrahends and high subtrahends. Tests of between-subjects effects showed that there was a significant difference between the groups ($p < 0.001$) in both conditions (in favour of the controls) between the age bands ($p < 0.001$) and a significant intercept of group and age band on low subtrahends ($p < 0.05$) but not on high subtrahends (ns). When comparing the mean response times across the conditions, all group age bands responded quicker on LN/LC ($p < 0.001$ and $p < 0.01$ for the old controls) except the young dyslexics (ns).

Comparing low/high subtrahends (LH) with not crossing/crossing (NC) the ten barrier

Figure 13.14 shows the difference in mean response times on LH and NC by group and age band. There was no significant difference between the groups on either condition, both on a comparison of all controls to all dyslexics and when comparing the groups in each age band. The difference in mean response times was greater on the NC condition than the LH condition for both groups in each age band. A group by age comparison of the difference in mean response times on the conditions is given in Table 13.22. This shows a ratio of greater difficulty for the young controls than the young dyslexics of 1 (NC) : 1.39 (LH) due to a floor effect whereby the poor performance of the dyslexics on both created a difference that was less marked. There was a ratio of greater difficulty for the medium-age dyslexics than the medium-age controls of 1 (NC) : 0.97 (LH) and a ratio of greater difficulty for the old dyslexics than the old controls of 1 (NC) : 3.85 (LH).

CHAPTER 14

Instantaneous Responding

14.1 Introduction

14.2 Three Time Bands

14.3 Aggregate of the Four Operations

14.4 Time Band 0–1.99 Seconds

14.5 Time Band 2–3.99 Seconds

14.6 Chapter Summary –The Question Answered

14.1 Introduction

This chapter is designed to answer one main question:

> Are non-dyslexics more likely than dyslexics to be able to respond instantaneously and correctly?

What constitutes an instantaneous response? This is a response that the participant gives automatically without the need to work out the answer; thus the participant responds without consciously calculating. The investigation by Pritchard et al. (1989) concentrated on multiplication number facts. They raised the issue of whether people could respond 'in one'. The participant was asked for the answers to all products up to 16 × 16. The participant heard the question and then responded verbally in one of three ways: by giving the immediate answer, by saying 'don't know' or by saying 'working out'. Such an approach was not as accurate as measuring the actual time taken to perform mathematical sums. A more rigorous investigation involves the use of accurate measurement. The advantage of this experiment was that the computer software was designed to time the participants' response to questions involving all four operations. The response time data gathered ranged from under 1 second to 22 seconds.

In a search for an appropriate time that would count as 'instantaneous', the results from the Key Search Reaction Time Test were referred to. This test was administered initially and reported on in Chapter 4. For the purposes of comparison on all operations, the results of the (CA) controls were used. The results showed responses from all participants ranging from 164.8 milliseconds for the old controls to 215.5 milliseconds for the young dyslexics. The actual test involved a number appearing on the computer screen and by way of response the participant keyed in the same number on the number pad and then pressed the "Enter" key. Forty single- and two-digit numbers were presented individually in order to achieve an overall mean key search response time for each participant. This test used the same sized digits and placed them centrally on the computer screen in the area that the questions would appear in the Main Experiment. This test acted as a safeguard control for slowness of reading skills and also motor skills. An 'instantaneous response time' would therefore be slightly above those times found in the Key Search Reaction Time Test since additionally in the Main Experiment the participant had to process the question and arrive at an answer.

Two sets of participants took part in this research as detailed in Chapter 3. One set performed the Multiplication experiment and a second set took part in the Division, Addition and Subtraction experiments.

14.2 Three Time Bands

It was decided to find out the time by which most of the correct responses were given: 60% of the correct responses were given by 6 seconds. An 'instantaneous' response does not carry any precisely fixed boundaries and so a decision was made to create three time bands within 6 seconds in order to discover any difference of response between the dyslexics and the controls and to provide a choice of boundaries. These were:

(1) *0–1.99 seconds*. The longest Key Search Reaction Time was 0.22 seconds and very few responses were made in under one second in the Main Experiments. For the purposes of comparison between the dyslexics and the controls it was

decided to set the first time band at 0–1.99 seconds, as any response less than 1.99 seconds would not give enough time for conscious calculation.

(2) *2–3.99 seconds*. To allow for a slower processing speed for the dyslexics, a time band of 2–3.99 seconds was established to register potentially automatic dyslexic responses where the dyslexics may have needed time to 'register a question' prior to responding.

(3) *4–5.99 seconds*. A third time band of 4–5.99 seconds was chosen to complete an analysis of correct responses made in less than 6 seconds.

The total number of correct responses was calculated in order to determine the time band in which most responses were made. From this information, comparisons could be drawn between the dyslexics and controls. Were the dyslexics able to answer as many questions correctly as the non-dyslexics within the same fast time bands?

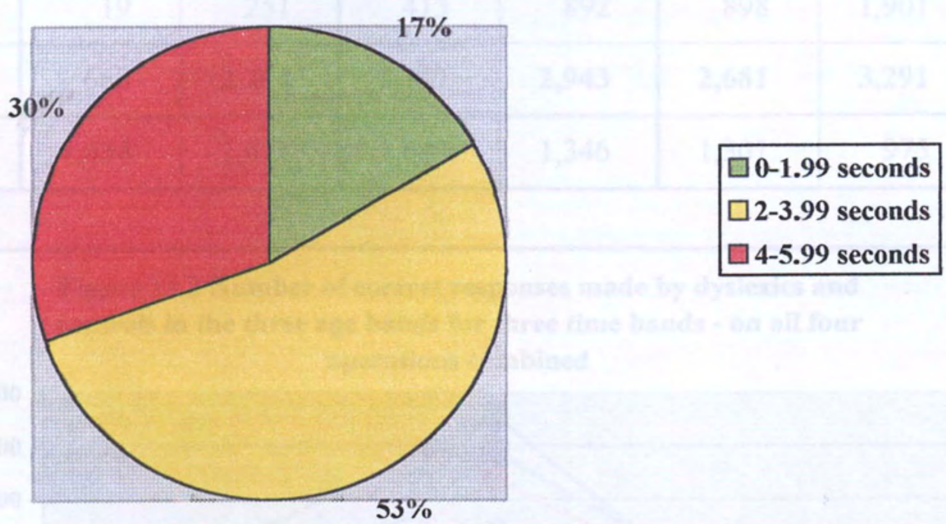
Table 14.1 gives the total of the raw scores that fell within each of these time bands. These were correct responses made by all participants (groups and age bands combined) on all trials for all operations. The results have been converted to a percentage and are represented in Figure 14.1.

Table 14.1 Total number of responses made by all dyslexics and controls on time bands under 6 seconds

Time bands	*Number of responses*
0–1.99 seconds	4,374
2–3.99 seconds	13,896
4–5.99 seconds	7,952

This gives a total of 26,222 out of a maximum of 43,920 questions asked.

Figure 14.1 Percentage of total number of responses within three time bands under 6 seconds



Thus the majority of questions were answered correctly in 2–3.99 seconds – this represents 53% of the correct responses given in under 6 seconds. Of these responses, how many were made by the dyslexics? Did age have an effect?

14.3 Aggregate of the Four Operations

The correct response times were recorded for each participant and scores collated for the three time bands chosen above. The results are displayed in Table 14.2. The scores presented in **bold** are those that are the highest for each group and age band. Figure 14.2 illustrates these results. Table 14.3 gives the ratio of correct responses for dyslexics and controls in the three age bands for the two fastest time bands – all four operations combined.

Table 14.2 Number of correct responses made by dyslexics and controls in the three age bands for three time bands – on all four operations combined

Time band (seconds)	*Young*		*Medium-age*		*Old*	
	Dyslexics	*Controls*	*Dyslexics*	*Controls*	*Dyslexics*	*Controls*
0–1.99	19	251	413	892	898	1,901
2–3.99	660	**2,214**	**2,107**	**2,943**	**2,681**	**3,291**
4–5.99	**1,034**	1,671	1,625	1,346	1,301	975

Figure 14.2 Number of correct responses made by dyslexics and controls in the three age bands for three time bands - on all four operations combined

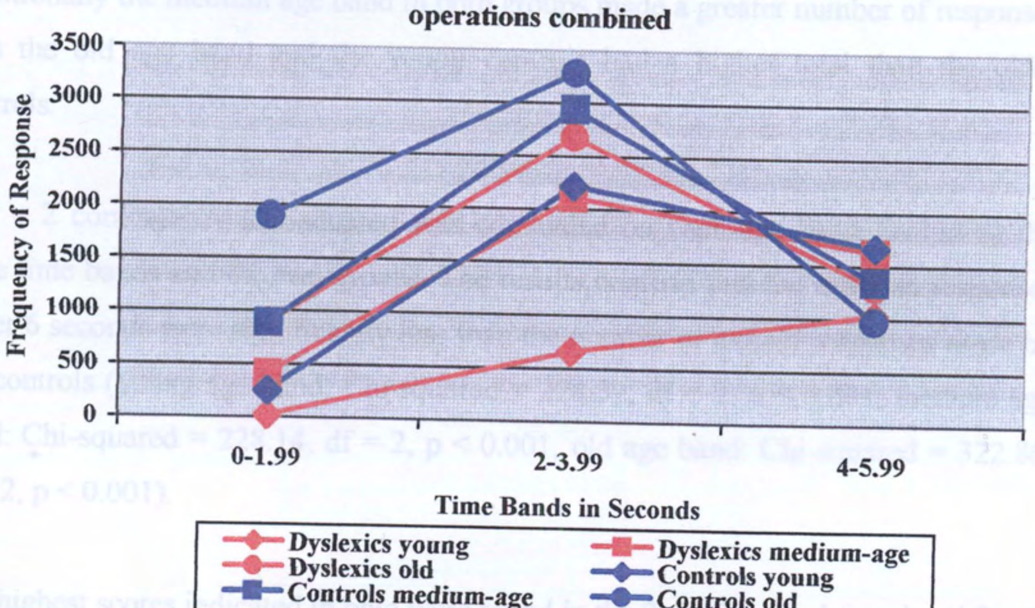


Table 14.3 Ratio of correct responses for dyslexics and controls in the three age bands for the two fastest time bands – all four operations combined

Time band (seconds)	*Young*		*Medium-age*		*Old*	
	Dyslexics	*Controls*	*Dyslexics*	*Controls*	*Dyslexics*	*Controls*
0–1.99	1 : 13.21		1 : 2.16		1 : 2.12	
2–3.99	1 : 3.35		1 : 1.40		1 : 1.23	

By taking the fastest time band (0–1.99 seconds) the ratio of correct responses was in favour of the controls in each age band, with the largest difference being in the young age band with a ratio of 1 : 13.21.

Within both the 0–1.99 second and 2–3.99 second time bands the controls made significantly more correct responses than the dyslexics in each age band (results are presented in section 14.4 and 14.5). As group age increased so too did the number of correct responses.

The pattern of responses was different for the 4–5.99 second time band. The dyslexics made more responses in both the medium and old age bands than the controls. Additionally the medium age band in both groups made a greater number of responses than the old age band and the young controls had a higher total than the older controls.

A 3 × 2 contingency Chi-squared was conducted on each age band, including the three time bands and the two groups. The results confirm that the dyslexic responses under 6 seconds were significantly less than the number of correct responses made by the controls (young age band: Chi-squared = 224.37, df = 2, $p < 0.001$, medium age band: Chi-squared = 228.14, df = 2, $p < 0.001$, old age band: Chi-squared = 322.86, df = 2, $p < 0.001$).

The highest scores indicated in bold were found in the 2–3.99 second time band for all groups and age bands except the young dyslexics, whose highest score was in the

4–5.99 second time band. The scores for the old dyslexics resemble those of the medium-age controls in each time band and likewise the results for the medium-age dyslexics resemble those found for the young controls except in the 0–1.99 second time band.

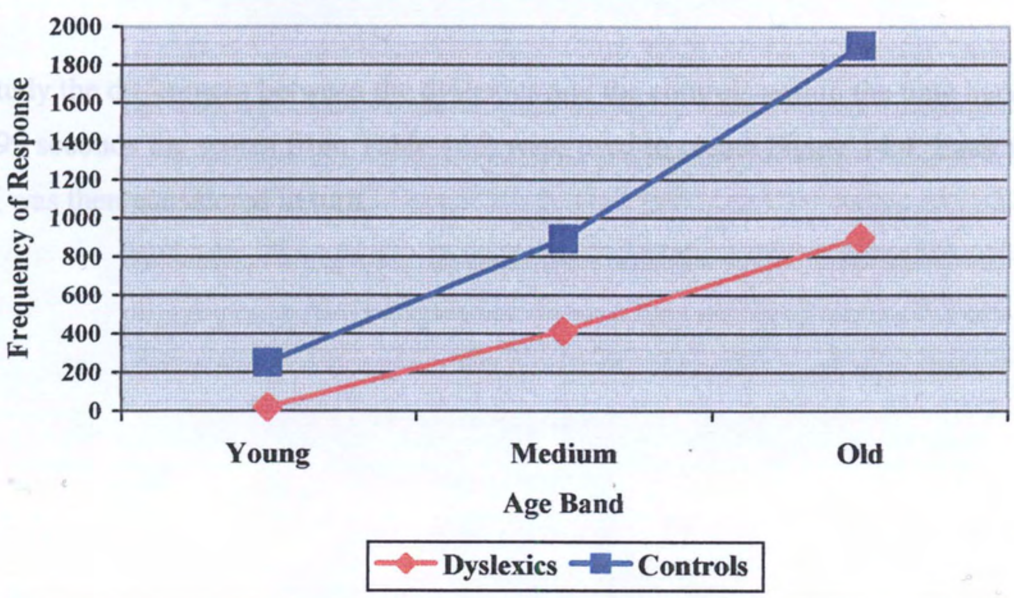
Therefore in a search for the time value that most accurately represents an instantaneous response, it seems more likely that the two quickest time bands are more indicative. Therefore responses timed at 0–4 seconds were chosen for further comparisons.

14.4 Time Band 0–1.99 Seconds

Responses from 0–1.99 seconds most closely represent 'instantaneous' responses and emphasis is placed on the results in this time band.

To study the differences between the dyslexics and the controls within the time band 0–1.99 seconds the scores from Table 14.2 were used to create Figure 14.3. Each age band was then considered in turn.

Figure 14.3 Number of correct responses made between 0 - 1.99 seconds by dyslexics and controls



A comparison of the presence and absence of correct responses within this time band was made between the two groups in each age band. Using a two-by-two design, Chi-squared tests showed that the dyslexics in each age band were answering significantly fewer questions correctly within this time band than the controls:

- Young comparisons: Chi-squared = 201.35, df = 1, $p < 0.001$
- Medium-age comparisons: Chi-squared = 192.22, df = 1, $p < 0.001$
- Old comparisons: Chi-squared = 443.49, df = 1, $p < 0.001$

The difference in number of responses between the dyslexics and controls increased the older the age band. The controls made more responses than the dyslexics in each age band. These were:

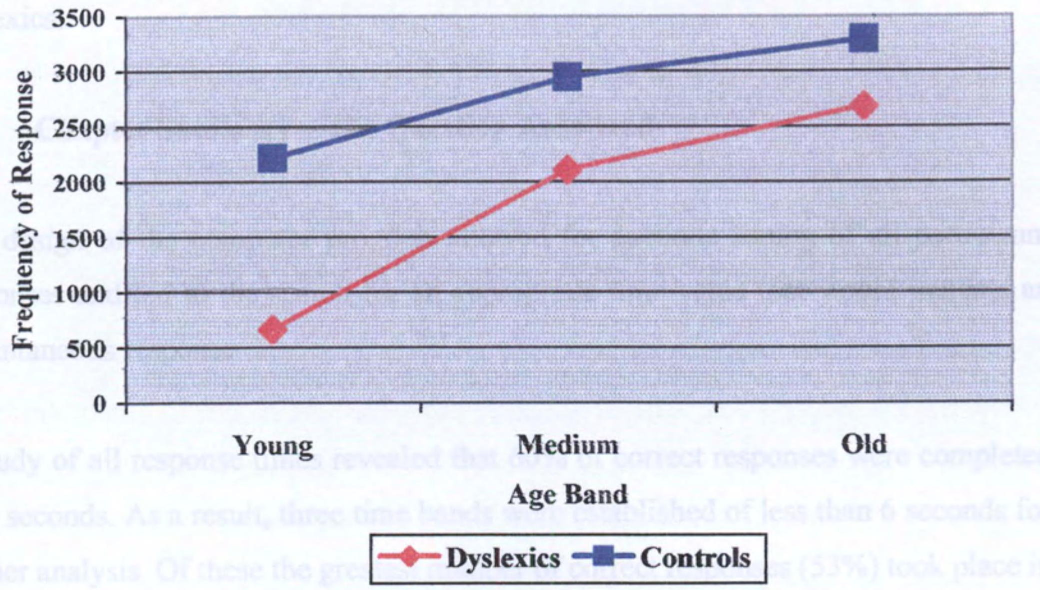
- Young = 232 more responses
- Medium-age = 479 more responses
- Old = 1,003 more responses

The rise in correct responses over the age bands increased for the dyslexics but there was a greater increase from the medium-age to the old age band for the controls.

14.5 Time Band 2–3.99 Seconds

To study the differences between the dyslexics and the controls within the time band 2–3.99 seconds the scores from Table 14.2 were used to create Figure 14.4. Each age band was then considered in turn.

Figure 14.4 Number of correct responses made between 2-3.99 seconds by dyslexics and controls



A comparison of the presence and absence of correct responses within this time band was made between the two groups in each age band. Using a two-by-two design, Chi-squared tests showed that the dyslexics in each age band were answering significantly fewer questions correctly within this time band than the controls:

- Young comparisons: Chi-squared = 1044.2, df = 1, $p < 0.001$
- Medium-age comparisons: Chi-squared = 210.77, df = 1, $p < 0.001$
- Old comparisons: Chi-squared = 104.89, df = 1, $p < 0.001$

The difference in number of responses between the dyslexics and controls decreased the older the age band. The controls made more responses than the dyslexics in each age band. These were:

- Young = 1,554 more responses
- Medium-age = 836 more responses
- Old = 610 more responses

The number of correct responses increased steadily over the age bands for the controls. This increase was more marked between the young to medium-age dyslexics.

14.6 Chapter Summary – The Question Answered

The design of the computer program allowed for accurate timing of all participant responses and led to the search for an appropriate time value that would indicate an instantaneous response.

A study of all response times revealed that 60% of correct responses were completed by 6 seconds. As a result, three time bands were established of less than 6 seconds for further analysis. Of these the greatest number of correct responses (53%) took place in the time band 2–3.99 seconds as compared to 17% for 0–1.99 seconds and 30% for 4–5.99 seconds.

While these results accounted for both the dyslexic and control groups and all age bands together, one of the questions established at the outset (in Chapter 2) was to find out if non-dyslexics were more likely than dyslexics to be able to respond instantaneously to sums involving the four operations. Therefore data for each group and age band was collected and the results for all four operations combined.

A pattern emerged that favoured the quickest time band of 0–1.99 seconds as the most representative of an 'instantaneous' time value. This was also in line with the findings from the initial Key Search Reaction Time Test.

Within the quickest time band of 0–1.99 seconds:

- The young controls correctly responded 251 times compared to 19 times by the young dyslexics (a ratio of 1:13.21). This represented the greatest proportional difference between the dyslexics and non-dyslexics in results under 4 seconds.

- The non-dyslexics in the medium-age and old age bands responded 892 and 1,901 times respectively as compared to 413 and 898 times respectively by the medium-age and old dyslexics.
- The gap in number of responses between the groups increased with increasing age.

Within 2–3.99 seconds:

- The non-dyslexics in the young age band answered 2,214 questions correctly compared to 660 questions by the young dyslexics. The difference between the dyslexics and non-dyslexics was greatest in this age band. The gap in number of responses between the groups decreased with increasing age.

Therefore the overall results showed that non-dyslexics were significantly able to respond instantaneously on more occasions than the dyslexics, particularly in the young age band.

An operational definition of an 'instantaneous' answer was chosen to be a response made within 1.99 seconds.

The next chapter presents details on a range of additional behavioural responses observed during the testing.

CHAPTER 15

Additional Behaviour

15.1 Introduction
15.2 Four Main Categories of Behaviour
15.3 Dyslexics Compared to Controls
15.4 Behaviours and Age
15.5 Category and Operation
15.6 Additional Behaviour Made By Individual Dyslexic and Control Participants in Stage 2 on Categories and Operations
15.7 Chapter Summary – Questions Answered

15.1 Introduction

This chapter is designed to address the following question:

> Is the behaviour of dyslexics when responding different from that of non-dyslexics?

During the pilot studies, dyslexic participants seemed to be making a range of additional behavioural responses that were different from and more numerous than those of the controls. It was decided to keep a record of this behaviour, including the actual words spoken. The aim was to gain data on any potentially significant differences in behaviour between the groups while responding on the computer. Some examples are given here. Each participant was given a number that is referred to in both this chapter and in Appendix G, as follows:

D1 – D10 Young dyslexics
C1 – C10 Young controls
D11 – D20 Medium-age dyslexics

C11 – C20	Medium-age controls
D21 – D30	Old dyslexics
C21 – C30	Old controls

See Appendix G for an account of observations made in each experiment.
Participants who took part in Stage 1 – Multiplication have been underlined (i.e. D3) in section 15.2.

15.2 Four Main Categories of Behaviour

Consideration was given as to how best to group the additional behaviours into categories. Miles (1993) observed that some dyslexics used their fingers on the Subtraction and Tables items of the Bangor Dyslexia Test and dyslexic participants in this research had also been observed using their fingers. It was therefore decided to create a category (Category A) for the use of fingers. Ashcraft and Fierman (1982) had found that half of their 3rd Grade participants had used some form of counting strategy for simple mental addition as opposed to retrieval from memory. Some participants in this research were observed to vocalise about the question and/or the working out of an answer. This audible vocalisation was recorded under Category C.

There were two other main types of additional behaviour that were observed during the course of the Main Experiments. These were bodily movements beyond the requirements of the test situation (Category B) and other audible vocalisation that included exclamations (Category D) (Miles, T.R., 2002, personal communication).

Behaviour which belongs in any of these four categories will be referred to as 'classified behaviour'.

Category A: *use of fingers* in working out an answer. This included finger strategies for multiplication tables.

Category B: *other bodily movement* made including if participants moved parts of their body overtly as compared to sitting quietly without any undue movement over and above the requirements of the experiment.

Examples of this behaviour included:

- itching legs, head, neck, wrist and nose (D12 – multiplication);
- waving hands above keys (D1 - multiplication);
- searching for keyboard numbers and then checking up on the screen to see if the numbers have been typed the wrong way around (D2 – multiplication);
- toes feeling the table leg (in between the big toe and the next toe) (D22 – division);
- leg moving (C4 – addition);
- lifting number pad, tilting head, itching centre of back (D29 – subtraction);
- hand over mouth, liked to cover nose and mouth to think, running fingers through fringe (D13 – multiplication);
- on 2 × 8 the participant suddenly jumped forward as though the answer had just struck him but it was a 'Miss' (took over 22 seconds) (D4 – multiplication);
- moving around a lot – adjusting glasses, sniffing, scratching (D15 – multiplication);
- foot moving up and down – rhythmical tapping, rolling up sleeves (D7 – division);
- closed eyes to think (D21 – multiplication);
- rubbing nose after every answer (D16 – multiplication).

Category C: *audible vocalisation* – relating to the question, for example where the participant repeated the question out loud or sub-vocalised when working out the answer. Examples of this behaviour included:

- '5 × 8 = 4, 2 × 9 = 16 . . . Oh no its not', '1 × 4 = 3 . . . Oh got that one wrong . . . 4' (D1 – multiplication);
- using the 5 times table as a basis on which to work out 7 × 6 (7 × 5 = 35 . . .), 7 × 12 . . . '70, that's 14 = 84', 9 × 6 = 64 . . . 'Oh its 54' was said two questions later (D14 – multiplication);
- verbalising quietly – only speaking the question and not the working out or the answer, sometimes doesn't finish speaking the question if he knows the answer quickly (C1 – division);

- echoing the question and working out loud, $45 + 4$ 'Oh that's easy' (said after about 15 seconds), needed time to log into the question (D3 – addition);
- verbalising the answer ready for typing in, echoing the question (C20 – subtraction).

Category D: *other audible vocalisation.* This included any comments or observations made about the experiment while in progress or any 'Oh no' type comments, including big sighs or a particularly deep breath. There were some instances where the participant typed in part of an answer (only one digit) and then realised the error and called out the correct answer. These instances were recorded and are placed under this category. Examples of this behaviour included:

- 'Its gone. I just had it' (<u>D2</u> – multiplication);
- 'Oh bother' (<u>D7</u> – multiplication);
- 'I'm rushed. If I had more time I could work it out . . . I get muddled up' (<u>D15</u> – multiplication);
- saw the question $108 \div 9$ and choked jokingly (indicating that this question was hard for him) (D2 – division);
- 'I hate division' (said very sweetly), big inhalation with a difficult question as though working up to making a decision (as to whether to pass etc.) (D22 – division);
- 'Can't they put one number above another?'(D3 – addition);
- 'Come on!'(D14 – addition);
- 'I am reacting too soon – jumping the gun – and pressing the wrong keys because of it' (C13 – addition);
- sighing (D15 – subtraction);
- 'I am slow at thinking' (<u>D29</u> – multiplication);
- $10 \times 11 = 100$ 'I want 110. Oh flip', $11 \times 10 = 101$ 'Oh, I've done it again, 110 again', $10 \times 10 = 110$ 'This time', $10 \times 2 = 10$ 'Oh no, 20', $11 \times 10 = 100$ 'Oh no, 110', $2 \times 2 = 2$ 'Oh no, it's 4', said that his mind was full up and he found it hard to move with a clear mind onto the next question (<u>D19</u> – multiplication);
- $1 \times 11 = 11$ 'I could hardly get that one back to front' (<u>D2</u> – multiplication).

Three questions are addressed in the following sections, namely:

(1) Do dyslexics do more of these things (all categories combined) than controls?

(2) Do these behaviours disappear with age for the dyslexics and the controls?

(3) Which category of behaviour is most prevalent for dyslexics and non-dyslexics and which operation is associated with the most number of behaviours?

15.3 Dyslexics Compared to Controls

(1) *Do dyslexics do more of these things (all categories combined) than controls?*

The 'classified' behaviour of all dyslexics was compared to all controls (age bands combined) by combining categories. A count was made of the number of participants in each group that made these responses including number of trials. The results are given in Table 15.1.

Table 15.1 Overall count of classified behaviour during responding

Groups	*Present*	*Absent*
Dyslexics	264	336
Controls	103	497

Chi-squared = 100.49, df = 1, $p < 0.001$

It may be concluded that the dyslexics do show more of these behaviours than non-dyslexics.

15.4 Behaviours and Age

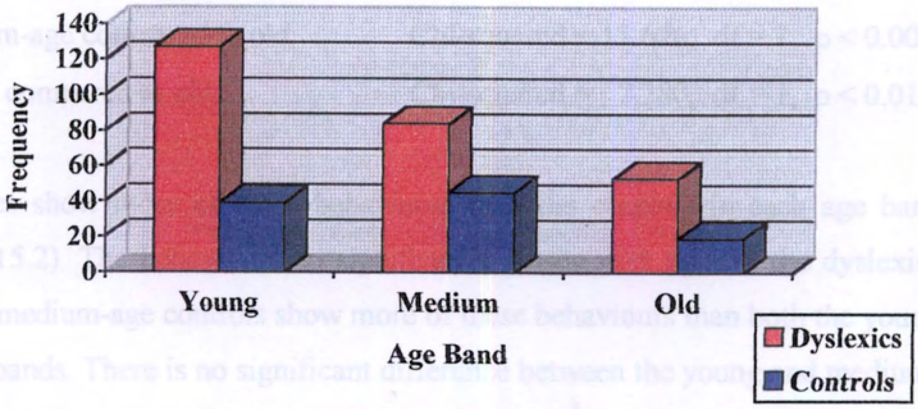
(2) *Do these behaviours disappear with age for the dyslexics and the controls?*

A count was made of the number of participants in each group that showed classified behaviour. Table 15.2 shows the count, for each group age band (all categories combined). This is illustrated in Figure 15.1.

Table 15.2 Count of present and absent classified behaviours for all categories combined by group age band

Age bands	*Groups*	*Present*	*Absent*
Young	Dyslexics	127	73
	Control	39	161
Medium	Dyslexics	84	116
	Control	45	155
Old	Dyslexics	53	147
	Control	19	181

Figure 15.1 Count of classified behaviours (combined) for each group and age band



A trend analysis for the two groups on age showed no significant difference overall (Chi-squared = 0.94, df = 4, ns).

A 2 × 2 Chi-squared test was conducted on dyslexics and non-dyslexics within each age band with the following results:

- Young dyslexics compared to young controls:
  Chi-squared = 77.943, df = 1, $p < 0.001$
- Medium-age dyslexics compared to medium-age controls:
  Chi-squared = 16.522, df = 1, $p < 0.001$
- Old dyslexics compared to old controls:
  Chi-squared = 18.445, df = 1, $p < 0.001$

A 2 × 2 Chi-squared test was conducted on age bands within groups with the following results:

Dyslexics:

- Young compared to medium-age: Chi-squared = 17.694, df = 1, $p < 0.001$
- Medium-age compared to old: Chi-squared = 9.991, df = 1, $p < 0.01$
- Young compared to old: Chi-squared = 53.828, df = 1, $p < 0.001$

Controls:

- Young compared to medium-age: Chi-squared = 0.3767, df = 1, ns
- Medium-age compared to old: Chi-squared = 11.626, df = 1, $p < 0.001$
- Young compared to old: Chi-squared = 7.280, df = 1, $p < 0.01$

The dyslexics show more of these behaviours than the controls in each age band (see Figure 15.2). The behaviours do significantly lessen with age for the dyslexics whereas the medium-age controls show more of these behaviours than both the young and old age bands. There is no significant difference between the young and medium-age controls.

15.5 Category and Operation

(3) *Which category of behaviour is most prevalent for dyslexics and non-dyslexics and which operation is associated with the most number of behaviours?*

The number of behaviours by category and operation and the percentages for each are presented in Table 15.3 (dyslexics) and Table 15.4 (controls).

Table 15.3 Number of behaviours per category and operation by the dyslexic group

Operation	*Category of behaviour*				*Operation total*	*Group total*
	A	*B*	*C*	*D*		
×	26	21	28	48	123 (51%)	264 out of 600 (44%)
÷	9	11	10	14	44 (37%)	
+	12	14	12	21	59 (49%)	
−	9	8	8	13	38 (32%)	
Total	56 (37%)	54 (36%)	58 (39%)	96 (64%)	264	

Category D accounted for the highest percentage of behaviours by the dyslexic group across operations, followed by category C, A and then B.

The behaviours occurred most often in multiplication, then addition, division and subtraction.

Table 15.4 Number of behaviours per category and operation by the control group

Operation	*Category of behaviour*				*Operation total*	*Group total*
	A	*B*	*C*	*D*		
×	6	9	6	41	62 (26%)	103 out of 600 (17%)
÷	3	1	4	2	10 (8%)	
+	7	4	9	3	23 (19%)	
–	4	1	3	0	8 (7%)	
Total	20 (13%)	15 (10%)	22 (15%)	46 (31%)	103	

Category D accounted for the highest percentage of behaviours by the control group across operations, followed by category C, A and then B.

The behaviours occurred most often in multiplication, then addition, division and subtraction.

The order of categories and operations was the same for both groups.

Group performance was compared on each operation and category using Chi-squared and Fisher's Exact Tests (2 × 2 design). These results are given in Table 15.5.

Table 15.5 Chi-squared and Fisher's Exact Test results with significant levels comparing the groups (age bands combined) on operation and behaviour category

Operation	*Category of behaviour*			
	A	*B*	*C*	*D*
×	15.384***	5.378 *	18.098 ***	1.566
÷	2.604	8.438 **	2.329	10.313 **
+	1.232	6.429 *	0.2930	20.069 ***
−	1.571	4.706 *	1.781	14.141 ***

df = 1

Significance levels key:

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

In all cases where there is a significant difference the dyslexics showed more of the behaviours.

See Appendix G for Chi-squared and Fisher's Exact Test significance levels comparing the dyslexics and control groups by age band on multiplication (Table G5) and on operation (Table G6).

15.6 Additional Behaviour Made by Individual Dyslexic (D) and Control (C) Participants in Stage 2 on Categories and Operations

The type of classified behaviour made by individual participants during the Division, Addition and Subtraction experiments is presented in Table 15.6. A black box signifies the presence of a classified behaviour.

Table 15.6 Type of classified behaviour made by Stage 2 participants by operation

Participant number	*Category*											
	A			*B*			*C*			*D*		
	÷	+	−	÷	+	−	÷	+	−	÷	+	−
D1	■		■	■	■	■	■	■	■	■	■	■
D2	■	■	■	■	■					■	■	■
D3	■	■			■	■	■	■	■	■	■	■
D4		■		■			■		■	■	■	■
D5	■	■	■				■	■	■	■		■
D6		■									■	
D7			■	■			■	■				
D8	■		■	■	■	■					■	
D9		■				■					■	■
D10		■		■	■	■		■		■	■	■
D11	■	■	■		■						■	
D12		■					■					
D13												
D14	■		■		■		■	■	■		■	
D15					■			■	■	■	■	■
D16								■				■
D17												
D18	■	■	■	■	■	■	■	■	■	■	■	■
D19				■	■	■					■	■
D20								■		■	■	■
D21											■	

D22		■		■						■	■	
D23										■	■	
D24											■	
D25				■							■	
D26	■			■			■			■	■	■
D27										■		
D28												
D29					■	■	■	■	■		■	
D30		■	■					■		■		
C1							■	■	■			
C2		■										
C3	■	■	■									
C4					■			■		■		
C5												
C6					■			■			■	
C7		■										
C8												
C9								■				
C10	■											
C11												
C12	■											
C13								■				
C14		■	■	■		■		■	■			
C15												
C16		■						■				

C17												
C18											■	
C19		■	■		■						■	
C20		■	■		■		■	■	■	■		
C21												
C22												
C23												
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C25							■	■				
C26												
C27												
C28												
C29												
C30							■					

Note. A classified behaviour was included as present by combining observations made across two trials where applicable.

The dyslexics make more classified behaviours.

For additional details on the classified behaviour of individual participants in Stage 1 (multiplication) see Appendix H (Table H.1).

15.7 Chapter Summary – Questions Answered

Is the behaviour of dyslexics when responding, different from that of non-dyslexics?

(1) *Do dyslexics do more of these things (all categories combined) than controls?*

By comparing the number of participants in each group that showed the 'classified' behaviours, the dyslexic count was 264 present to 103 present for the controls out of a maximum of 600. This was found to be statistically significant (Chi-squared = 100.49, df = 1, $p < 0.001$). Thus the dyslexics showed significantly more of these behaviours than non-dyslexics.

The dyslexics also showed significantly more 'classified' behaviours than the controls in each age band ($p < 0.001$) (see Table 15.2).

(2) *Do these behaviours disappear with age for the dyslexics and the controls?*

There was no significant difference for trend between the groups on age.

The number of 'classified' behaviours decreased with age for the dyslexics (young = 127, medium-age = 84, old = 53). There was a significant difference between the young and medium age band ($p < 0.001$), between the medium and old age band ($p < 0.01$) and between the young and old age band ($p < 0.001$).

The number of 'classified' behaviours did *not* necessarily decrease with age for the controls (young = 39, medium-age = 45, old = 19) where the young age band scored less than the medium age band but more than the old age band. There was a significant difference between the medium and old age band ($p < 0.001$) and the young and old age band ($p < 0.01$) but not between the young and medium age band (ns).

(3) *Which category of behaviour is most prevalent for dyslexics and non-dyslexics and which operation is associated with the most number of behaviours?*

The order of number of responses for categories of behaviour and occurrence in the operations (from greatest to least) was the same for both groups, as follows:

- Category: D, C, A and B
- Operation: multiplication, addition, division and subtraction

The dyslexics showed significantly more Category *B* and *D* behaviours on all operations (except multiplication in category D) compared to the controls. The dyslexics also showed significantly more classified behaviours on ***multiplication*** (Category A ($p < 0.001$), B ($p < 0.05$) and C ($p < 0.001$)) when compared to the controls, than on any other operation (see Table 15.6).

Therefore, the behaviour of dyslexics when responding *is* different from that of non-dyslexics.

The next chapter compares the results on the four operations.

CHAPTER 16

Comparing the Four Operations

16.1 Introduction

16.2 Correctness

16.3 Speed

16.4 Instantaneous Responding

16.5 Chapter Summary

16.1 Introduction

In this chapter a comparison is made of the performance of dyslexics and non-dyslexics on the four operations. Comparison data are drawn from results on correctness and speed presented in Chapters 6–14.

16.2 Correctness

The results on the performance of dyslexics and non-dyslexics on correctness for each operation are presented, with a study of the order of difficulty of the operations, 'tables' and categories, for each group.

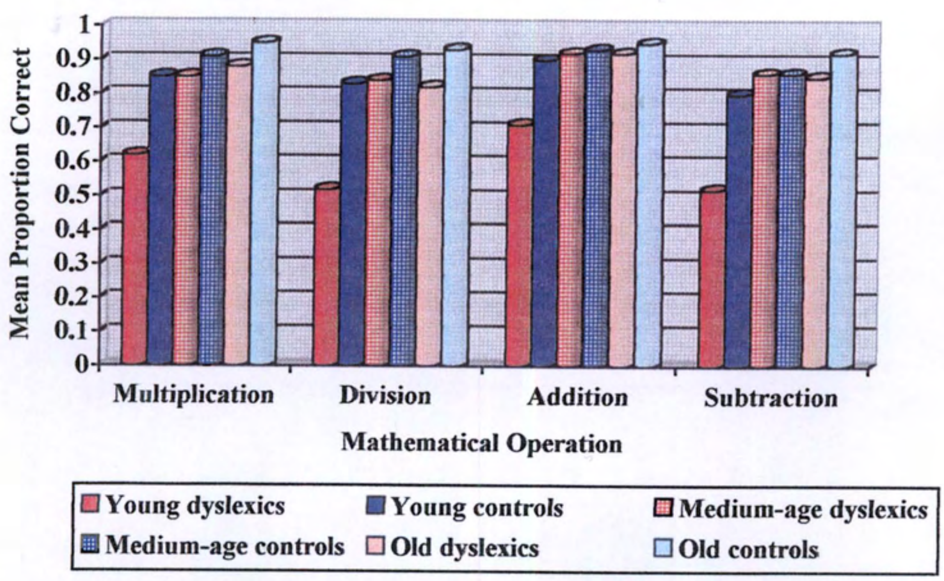
16.2.1 Mean Proportion of Correct Responses in each Operation

Combining the findings for each operation, on correctness, the results for each group and age band are given in Table 16.1 and Figure 16.1.

Table 16.1 Mean proportion of correct responses by group and age band on the four operations

Groups	*Age bands*	*Operation*			
		×	÷	+	−
Dyslexics	Young	0.62	0.52	0.71	0.52
	Medium	0.85	0.84	0.92	0.86
	Old	0.88	0.82	0.92	0.85
Controls	Young	0.85	0.83	0.90	0.80
	Medium	0.91	0.91	0.93	0.86
	Old	0.95	0.93	0.95	0.92

Figure 16.1 Comparison of mean proportion of correct responses for different operations by group and age



Comparing the correctness of the responses across the age bands on each of the operations, it was found Spearman rho = 0.66, $p < 0.059$ (not quite significant) for the dyslexic group and for the controls Spearman rho = 0.82, $p < 0.01$. Thus there was a more pronounced correlation of performance from the young to medium-age to old age band showing a continuous improvement for the controls, whereas for the dyslexics there was a continuous improvement from the young to the medium age band, where performance on correctness reached a ceiling and there was no further improvement.

16.2.2 Order of Difficulty of the Mathematical Operations – Correctness

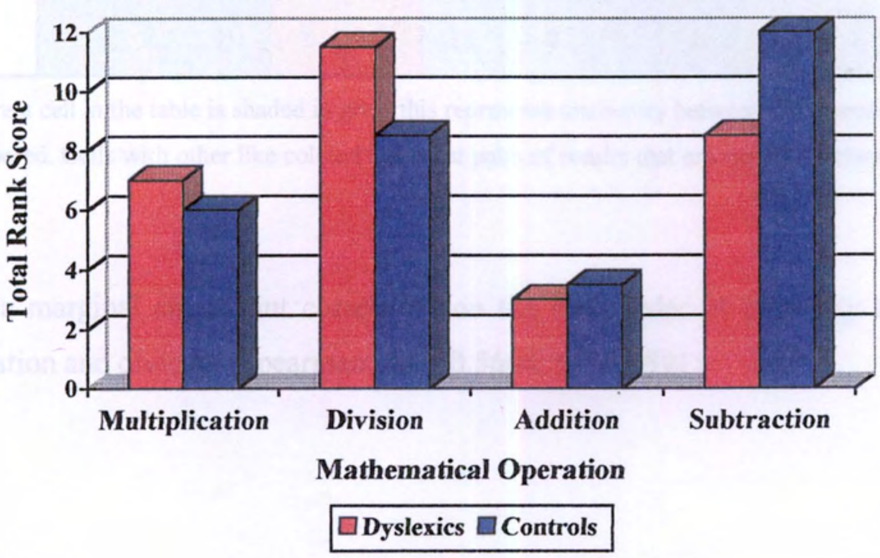
'Order of difficulty' is defined as the order in which the four operations are answered correctly, where an operation is more 'difficult' when more answers are incorrect.

The above results are organised in rank order showing the greatest to least mean proportion of correct responses for each operation. Table 16.2 and Figure 16.2 give these results by group and age band.

Table 16.2 Rank order on mean proportion of correct responses for each operation by group and age band

Groups	*Age bands*	*Operation*			
		×	÷	+	−
Dyslexics	Young	2	3.5	1	3.5
	Medium	3	4	1	2
	Old	2	4	1	3
Total		7	11.5	3	8.5
Order		2	4	1	3
Controls	Young	2	3	1	4
	Medium	2.5	2.5	1	4
	Old	1.5	3	1.5	4
Total		6	8.5	3.5	12
Order		2	3	1	4

Figure 16.2 Total rank scores on correctness for dyslexics and non-dyslexics on the four mathematical operations



A comparison was made between the totals for each group (age bands combined) on each operation. A correlation analysis indicated that there was an overall correlation but it was not statistically significant with so few numbers (Spearman rho = 0.8, ns).

The order of difficulty of the four operations for the dyslexics (from most to least correct) was: addition, multiplication, subtraction and division.

For the controls the order of difficulty was: addition, multiplication, division and subtraction.

16.2.3 Comparing Multiplication and Division Tables

The order of difficulty of the 'tables' is compared for Multiplication (Chapter 6) and Division (Chapter 7) with the results presented in Table 16.3. The rank order of difficulty is displayed from most (rank 1) to least correct (rank 12).

Table 16.3 Comparison of order of difficulty on correctness for multiplication and division tables

Operation	*Rank order of difficulty*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
×	1	2	10	3	5	4	11	6	9	7	8	12
÷	1	2	10	5	3	11	4	9	6	7	8	12

Note. Where a cell in the table is shaded in grey, this represents unanimity between the operations being compared. Cells with other like colours represent pairs of results that are reversed between the operations.

There is a marginal significant correlation on the rank order of difficulty between multiplication and division (Spearman rho = 0.5664, p = 0.0591).

16.2.4 Comparing Addition and Subtraction Categories

The order of difficulty of the 'categories' is compared for Addition (Chapter 8) and Subtraction (Chapter 9) with results presented in Table 16.4.

Table 16.4 Comparison of order of difficulty on correctness for addition and subtraction categories

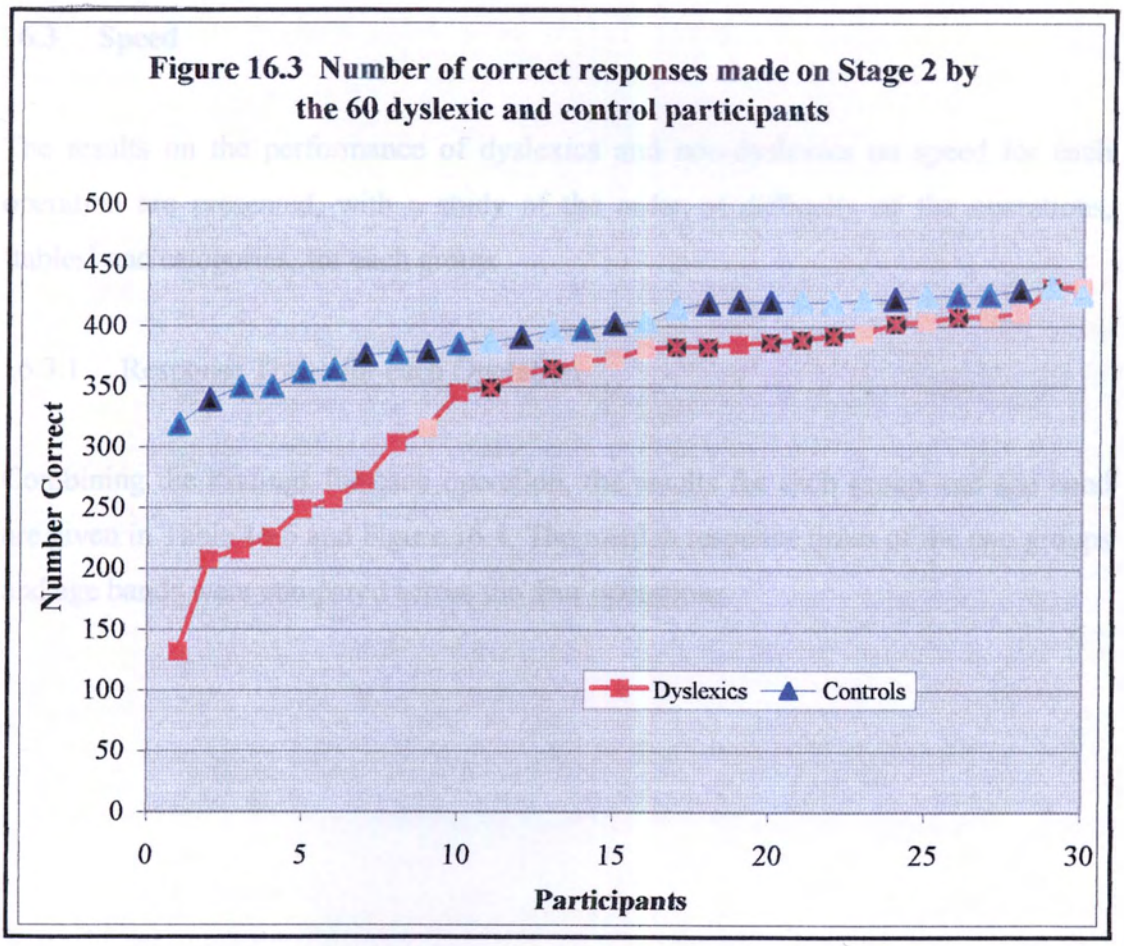
Operation	*Rank order of difficulty*				
	1	*2*	*3*	*4*	*5*
+	LN	HN	LC	HC	HARD
–	LN	HN	LC	HC	HARD

Note. Where a cell in the table is shaded in grey, this represents unanimity between the operations being compared.

Thus there are similarities in the order of difficulty between the pairs of operations.

16.2.5 Performance of Individuals in Stage 2

The number of correct responses made by individual participants on division, addition and subtraction (Stage 2) is shown in Figure 16.3. The participants have been colour coded to show which group (dyslexics = orange, controls = blue) and age band they belong to. The young age band is represented in strong orange or blue, the medium age band have a black background and the old age band are in pale orange or pale blue.



The maximum number of correct responses is 444 (division = 144, addition = 150 and subtraction = 150 questions asked).

Of the 30 dyslexics 28 made less correct responses than the controls. The two best performing dyslexics made one more correct response than the two best performing control participants.

The most correct young and medium-age dyslexic was 12th and 2nd respectively and the least correct old dyslexic was 22nd in the dyslexic group. The most correct young and medium-age control was 4th and 3rd respectively and the least correct old control was 20th in the control group. Thus the performance of the individuals was varied across the age bands in both groups.

16.3 Speed

The results on the performance of dyslexics and non-dyslexics on speed for each operation are presented, with a study of the order of difficulty of the operations, 'tables' and categories, for each group.

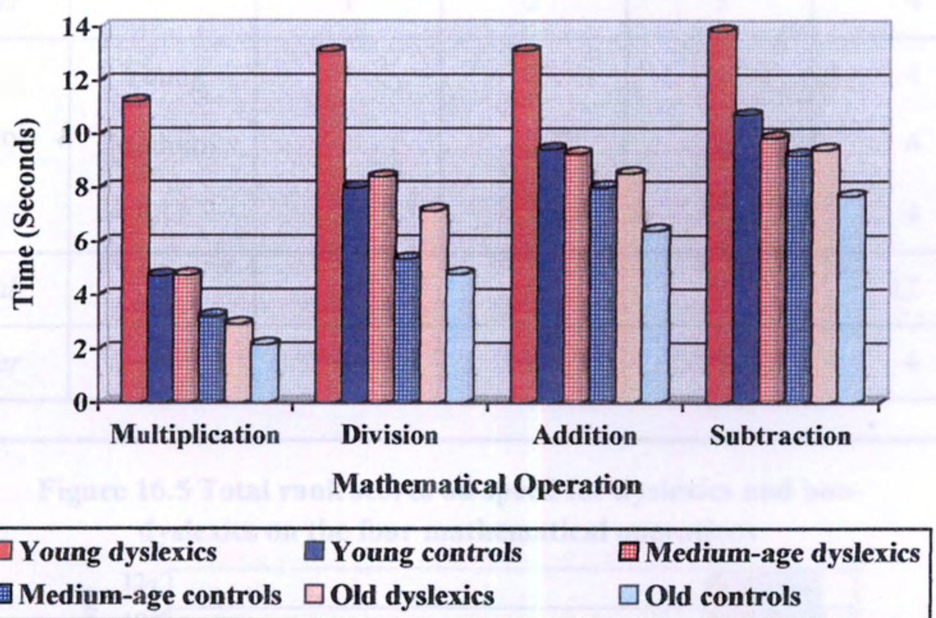
16.3.1 Response Times for each Operation

Combining the findings for each operation, the results for each group and age band are given in Table 16.5 and Figure 16.4. The median response times of the two groups and age bands were compared across the four operations.

Table 16.5 Response times (in seconds) by group and age band on the four operations

Groups	*Age bands*	*Operation*			
		×	÷	+	–
Dyslexics	Young	11.22	13.10	13.12	13.86
	Medium	4.75	8.41	9.27	9.87
	Old	2.94	7.15	8.54	9.41
Controls	Young	4.73	8.01	9.43	10.74
	Medium	3.23	5.35	8.02	9.21
	Old	2.18	4.79	6.41	7.69

Figure 16.4 Comparison of response times for different operations by group and age



There was a significant trend with age for the dyslexics from young to medium-age to old (Spearman rho = 0.79, $p < 0.02$).

There was also a significant trend with age for the controls from young to medium-age to old (Spearman rho = 0.74, $p < 0.05$).

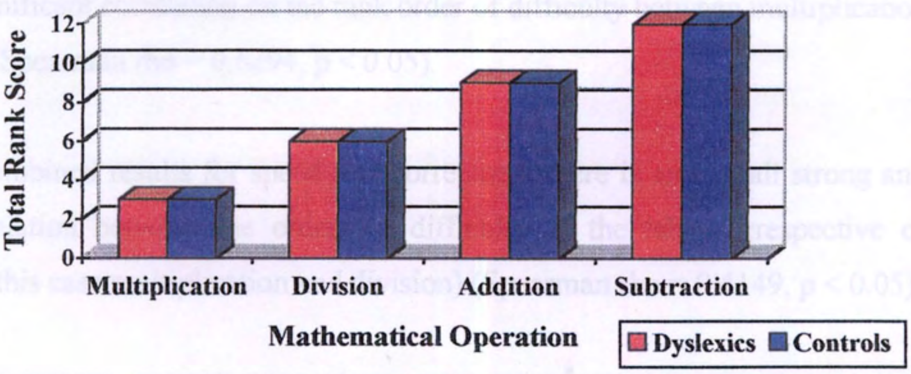
16.3.2 Order of Difficulty of the Mathematical Operations – Speed

The above results are organised in rank order showing the greatest to least response time for each operation. Table 16.6 and Figure 16.5 give these results by group and age band.

Table 16.6 Rank order on response times for each operation by group and age band

Groups	*Age bands*	*Operation*			
		×	÷	+	−
Dyslexics	Young	1	2	3	4
	Medium	1	2	3	4
	Old	1	2	3	4
Total		3	6	9	12
Order		1	2	3	4
Controls	Young	1	2	3	4
	Medium	1	2	3	4
	Old	1	2	3	4
Total		3	6	9	12
Order		1	2	3	4

Figure 16.5 Total rank scores on speed for dyslexics and non-dyslexics on the four mathematical operations



The total rank scores for both the dyslexics and non-dyslexics were the same (Spearman rho = 1, $p = 0.08$).

Thus the order of difficulty of the four operations for both groups, from quickest to slowest, was: multiplication, division, addition and subtraction.

16.3.3 Comparing Multiplication and Division Tables

The order of difficulty of the 'tables' is compared for Multiplication (Chapter 10) and Division (Chapter 11) with the results presented in Table 16.7. The rank order of difficulty is displayed in terms of the speed of responding from quickest (rank 1) to slowest (rank 12).

Table 16.7 Comparison of order of difficulty on speed for multiplication and division tables

Operation	*Rank order of difficulty*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
×	1	10	2	5	3	4	11	6	7	9	8	12
÷	1	10	2	5	3	11	4	6	9	7	8	12

Note. Where a cell in the table is shaded in grey, this represents unanimity between the operations being compared. Cells with other like colours represent pairs of results that are reversed between the operations.

There is a significant correlation on the rank order of difficulty between multiplication and division (Spearman rho = 0.6294, $p < 0.05$).

Taking the combined results for speed *and* correctness there is an overall strong and positive correlation between the orders of difficulty of the tables irrespective of operation (in this case multiplication and division) (Spearman rho = 0.4149, $p < 0.05$).

16.3.4 Comparing Addition and Subtraction Categories

The order of difficulty of the 'categories' is compared for Addition (Chapter 12) and Subtraction (Chapter 13) with results presented in Table 16.8.

Table 16.8 Comparison of order of difficulty on speed for addition and subtraction categories

Operation	*Rank order of difficulty*				
	1	*2*	*3*	*4*	*5*
+	LN	HN	LC	HC	HARD
–	HN	LN	LC	HC	HARD

Note. Where a cell in the table is shaded in grey, this represents unanimity between the operations being compared. Cells with other like colours represent pairs of results that are reversed between the operations.

16.4 Instantaneous Responding

The results of instantaneous responding by dyslexics and non-dyslexics were detailed in Chapter 14. As such, a response was counted as 'instantaneous' if made in less than 2 seconds. Two time bands were established that investigated the possibility of responses made with the minimum of conscious calculation; these were responses made between 0–1.99 seconds and 2–3.99 seconds.

The number of responses made by dyslexics and non-dyslexics on each mathematical operation is presented in Table 16.9 and Table 16.10. The column entitled 'maximum number' enables the reader to derive the percentage figures given.

Table 16.9 Number of correct responses in 0–1.99 seconds on each operation by group (percentages given in brackets)

Operation	*Maximum number (total questions × 60 participants*	*Group*		*Combined group total[#]*
		*Dyslexics**	*Controls**	
×	*17,280*	*884 (10%)*	*1,678 (19%)*	2,562 (15%)
÷	8,640	406 (9%)	976 (23%)	1,382 (16%)
+	9,000	30 (0.7%)	196 (4%)	226 (3%)
–	9,000	10 (0.2%)	194 (4%)	204 (2%)
Total	43,920	1,330	3,044	4,374

Note.

* Represents columns where the percentage has been found from the number correct out of the maximum number of questions per group (30 participants).

\# Represents the column where the percentage has been found from the number correct out of the maximum number of questions per groups combined (60 participants).

The controls answered significantly more questions correctly over the four operations in 0–1.99 seconds than the dyslexics ($t = 3.33$, $df = 3$, $p < 0.05$).

The order of operations, from greatest to least number of correct responses given in 0–1.99 seconds, is:

- Dyslexic group: multiplication, division, addition and subtraction
- Control group: division, multiplication, addition and subtraction
- Combined groups: division, multiplication, addition and subtraction

Table 16.10 Number of correct responses in 2–3.99 seconds on each operation by group (percentages given in brackets)

Operation	*Maximum number (total questions × 60 participants*	*Group*		*Combined group total#*
		*Dyslexics**	*Controls**	
×	17,280	2,544 (29%)	3,694 (43%)	6,238 (36%)
÷	8,640	1,228 (28%)	1,579 (37%)	2,807 (32%)
+	9,000	955 (21%)	1,820 (40%)	2,775 (31%)
–	9,000	721 (16%)	1,355(30%)	2,076 (23%)
Total	43,920	5,448	8,448	1,3896

Note.

* Represents columns where the percentage has been found from the number correct out of the maximum number of questions per group (30 participants).

\# Represents the column where the percentage has been found from the number correct out of the maximum number of questions per groups combined (60 participants).

The difference between the dyslexics and controls did not reach significance on the four operations ($t = 2.62$, $df = 3$, $p < 0.08$).

Therefore the order of operations, from greatest to least number of correct responses given in 2–3.99 seconds, is:

- Dyslexic group: multiplication, division, addition and subtraction
- Control group: multiplication, addition, division and subtraction
- Combined groups: multiplication, division, addition and subtraction

16.5 Chapter Summary

Mean Percentage of Correct Responses and Response Times for Each Operation

The dyslexics had a lower mean percentage of correct responses in all age bands and on all operations when compared to the non-dyslexics (except in the medium age band on subtraction where the result is the same for both groups). Young dyslexics showed proportionally lower scores than any other group age band on all the operations. The controls improved consistently with age across the four operations whereas the medium-age dyslexics had a higher mean percentage of correct responses than the old dyslexics on division and subtraction and had an equal score for addition.

The dyslexics had longer median response times than the controls in each age band and on every operation. The young dyslexics had proportionally longer median response times than any other group age band on each operation. Both groups improved on speed of responding with age.

Thus three main points emerged:

(1) The dyslexics were slower and less accurate than non-dyslexics on all operations.

(2) The young dyslexics were proportionally slower and less accurate than all other group age bands.

(3) While speed improved with age, this was not so for accuracy of the dyslexics.

Order of Difficulty of the Mathematical Operations – Correctness and Speed

There was an overall correlation on both correctness and on speed between the orders of difficulty of the four operations irrespective of group or age band.

The order of difficulty between correctness and speed varied. For example, the dyslexics were most accurate on addition but quickest on multiplication, as were the controls. The dyslexics were least accurate on division and slowest on subtraction whereas the controls were least accurate and slowest on subtraction.

Comparing Multiplication and Division Tables

Previously a strong and positive correlation had been found on the order of difficulty of the multiplication and division tables irrespective of group or age. This applied to both correctness (Chapter 6 and 7) and speed (Chapter 10 and 11).

A standard order of difficulty had thus been established for both operations, and comparisons were made between them.

- *The findings for correctness.* The results given in Table 16.3 showed that six (out of the twelve) tables were given the same ranking on both multiplication and division – these were tables 1, 2, 10 (ranked 1, 2 and 3), 7, 8 and 12 (ranked 10, 11 and 12). Of the remaining tables, these formed pairings that were reversed consecutively between multiplication and division – these were 3/5, 4/11 and 6/9.
- *The findings for speed.* The results given in Table 16.7 showed that eight (out of the twelve) tables were given the same ranking on both multiplication and division – these were tables 1, 10, 2, 5 and 3 (ranked 1, 2, 3, 4 and 5) 6, 8 and 12 (ranked 8, 11 and 12). Of the remaining tables, these formed pairings that were reversed consecutively between multiplication and division – these were 4/11 and 7/9.

The order of difficulty of tables showed that multiplication and division were approaching significant similarity on correctness ($p = 0.0548$) and were significant on speed ($p < 0.05$).

Comparing Addition and Subtraction Categories

The order of the five subtraction and addition categories are the same on correctness (from most to least correct): LN, HN, LC, HC and HARD.

The results are the same for speed except that HN is faster than LN for subtraction.

Instantaneous Responding – Speed

In *both* time bands under 4 seconds, the dyslexics made most 'instantaneous responses' on multiplication followed by division, addition and then subtraction, whereas the non-dyslexics made more 'instantaneous responses' on division in under 2 seconds (followed by multiplication, addition and then subtraction) and on multiplication in the time band 2–3.99 seconds (followed by addition, division and then subtraction). Subtraction was the mathematical operation with the least number of correct responses made in 0–1.99 seconds and 2–3.99 seconds by either group.

Next follows a discussion of the results with links made with different theories of dyslexia.

Part IV Discussion

CHAPTER 17

Discussion and Links with Different Theories of Dyslexia

17.1 Introduction
17.2 Acquisition
17.3 Age of Gain
17.4 Maturational Lag
17.5 Performance Anomalies
17.6 The Four Operations – Some Thoughts
17.7 Unexpected Age Difference (UAD)
17.8 Additional Behaviour
17.9 Overall Conclusion

17.1 Introduction

The research questions posed at the start of this thesis (see Chapter 2) are as follows:

When performing mathematical operations of multiplication, division, addition and subtraction:

(1) Do dyslexics make fewer correct responses and need more time to respond than non-dyslexics?
(2) Do younger dyslexics make fewer correct responses and are they slower than older dyslexics?
(3) Are there special number combinations that are more likely than others to generate errors and take more time?
(4) Are non-dyslexics more likely than dyslexics to respond 'instantaneously'?

(5) Is the behaviour of dyslexics when responding different from that of non-dyslexics?

A number of very interesting findings have emerged from this research. It has become apparent that some findings are as expected whereas others are surprising. This chapter is a discussion of the most interesting findings and how they relate to other research.

The hypotheses given in Chapter 2 read: On measures of speed and accuracy of response on the four mathematical operations, dyslexics will be disadvantaged in relation to non-dyslexics due to biological (including a cerebellar deficit), cognitive (including paired associate learning and automatisation deficit) and behavioural (including motor, memory and articulatory difficulties) factors that have been detailed in the Literature Search. The hypotheses were supported.

The predictions have all been supported:

1. The dyslexic participants, in comparison to the non-dyslexics, were less accurate and took longer to respond when performing the four mathematical operations.
2. The younger dyslexics, in comparison to older dyslexics, were less accurate and took longer to respond except in some instances where the medium-age dyslexics performed better than the old dyslexics.
3. Special number combinations in each operation, such as multiplication and division tables without obvious algorithms and addition and subtraction categories that have high addends/subtrahends or that cross the ten barrier, did generate more errors and took more time and that dyslexics will be differentially affected.
4. The non-dyslexics did respond to more questions instantaneously than the dyslexics.
5. The behaviour of the dyslexics was different to that of the non-dyslexics when performing the mathematical tasks.

Firstly, the performance of the young dyslexics is considered with a discussion on their acquisition of number facts.

17.2 Acquisition

The performance of the dyslexics in the young age band was particularly slower and less accurate than that of the young controls and also that of the medium-age dyslexics. Their weaker performance on the four mathematical operations was consistent and very obvious compared to the other group age bands. Thus if these participants are typical of dyslexics in general, their acquisition of number facts and calculating skills are lacking in comparison to the general population of school children from 9 years 5 months to 11 years 4 months.

We need to consider why it was that the young dyslexics did not perform as well. The answer may lie with a number of well-known theories of dyslexia: paired-associate learning, verbal labelling difficulties and automaticity.

That dyslexics have difficulty with paired-associate learning has been researched and discussed by Done and Miles (1978, 1988), Vellutino (1979), Vellutino et al. (1975) and Ackerman and Dykman (1995). One such paired-associate learning task was to present the participants with nonsense shapes for which novel names have to be learned (Done and Miles, 1978). When naming, the dyslexics needed to have the pairings presented on more occasions than the controls, before learning had taken place. In addition dyslexics were shown to have a longer response latency where they took longer to produce the right word in naming real pictures (Done and Miles, 1988). Related to this research, the young dyslexics had not yet learned pairings, such as learning the association between particular multiplicands and multipliers and their product (for example $6 \times 3 = 18$), sufficiently and to the same level as non-dyslexics. According to the findings for paired associate learning, they would need many more pairings of number facts, number bonds, borrowing and carrying situations before they were adequately proficient. Additionally the dyslexics would take longer to name the correct answer to the mathematical questions posed.

T.R. Miles (in Miles and Miles, 1992) emphasised that dyslexic weakness at paired-associate learning was not applicable to the learning of all associations, but more particularly to situations that require the understanding of symbols (and hence verbal labelling). The processing of linguistic material places the dyslexic in a disadvantageous position because of a deficiency at the level of lexical encoding (Ellis and Miles, 1981). Ellis and Miles (1981) used a model of an internal 'dictionary' (lexicon) to explain how we learn to talk. New words are entered into the dictionary in the lexicon, and these are retrieved from it when words are spoken correctly. This theory encompassed the deficiency of dyslexics in naming (i.e. accessing and retrieving words from the lexicon) visual stimuli. Thus a lexical encoding deficiency provides a possible description of how the young dyslexics had formed fewer entries in their internal lexicon for number facts and number bonds. In this research the mathematical questions were presented visually and it is presupposed that the participants relied on a visual–verbal association to determine the answer.

Done and Miles (1988) claimed that there was a link between naming speed and age of acquisition. They found that dyslexic boys of mean age 14 years 6 months were slower in 'finding' the correct word to name pictures of known objects and animals than controls. The age of acquisition of these names was determined from a study of young children and a correlation was found between the response latencies of the dyslexics and age of acquisition. Done and Miles therefore argued that on average dyslexics were later by a period of 10.8 months in acquiring names than their non-dyslexic peers. This begs the question as to whether dyslexics are affected by late acquisition of naming digits and if so, what effect may this have on the learning of number facts and number bonds and especially naming them at speed.

One might argue that once a number fact or bond has been learned, because of a sufficient number of 'pairings', it has become automatised. One possible way to describe the findings whereby the young controls were able to answer significantly more mathematical questions correctly and at speed could be to explain that they had built up more entries in their lexicon and were able to access these more automatically. Denkla and Rudel (1976) found that dyslexics could be differentiated from other learning disability candidates because they displayed a rapid 'automatized' naming (RAN) deficit when verbally responding to visual stimuli, and Ackerman et al. (1986) wrote of the failure of Reading Disabled (RD) children to 'automatize (memorize) basic number combinations'. Thus young dyslexics have an automatisation difficulty, which could explain their weaker performance on the mathematical questions.

Nicolson and Fawcett (1990) investigated the performance of 13-year-old dyslexic children on motor balance while making a choice reaction to tones. Dyslexic children found balance difficult when they were prevented from concentrating on it by being given a choice as to whether an auditory tone was high or low. When these two tasks were performed in conjunction, the dyslexic performance declined significantly compared to the controls. The findings prompted the authors to propose that dyslexia is a 'deficit in the acquisition of skill' where dyslexics have difficulty at becoming automatic at any skill. The 'dyslexic automatisation deficit' (DAD) hypothesis explained that dyslexic children needed to consciously compensate for their automatisation difficulties especially in dual-task settings where both speed and accuracy of response were affected.

That the young dyslexics in the present research showed the weakest performance of the three dyslexic age bands may indicate that automatisation is crucial for the acquisition of mathematical facts in the initial stages of learning. Sums involving small numbers, for example addends ranging from 2 to 5, are presented most frequently in school (Ashcraft et al., 1992) and smaller numbers such as the digits 1, 2 and 3 more commonly appear in print and in the world about us than higher digits (Dehaene, 1997). Thus automaticity will develop more readily for smaller arithmetical facts (Ashcraft et al., 1992) since the learner will have had more 'exposures' to the same stimulus (Miles et al., 2001).

Despite the greater number of 'exposures', the dyslexic is slow to pick up the familiar (Miles, 2002 – personal communication) as shown by the dyslexic difficulty in learning the correct sequence for the months of the year; a sub-item in the Bangor Dyslexia Test (Miles, 1993). Miles writes of two main factors influencing the learning of information like the months: 'the length of the series and the number of opportunities for learning it'. Number facts may appear numerous and unrelated and patterns within the mathematics will not be so readily registered as easily by the dyslexics as they are with the non-dyslexics. Therefore the young dyslexics in this research were particularly slow to pick up the most familiar number facts, even in the lower tables on multiplication and division (see the topographical terrains in Chapter 10 and 11). Thus in the young age band the dyslexics may not have 'absorbed' (Miles et al., 2001) as much as the controls.

Once acquisition has been achieved, this is reflected in particular gains in speed/accuracy of performing the mathematical questions. Next is a study of when these gains occurred for both the dyslexics and controls.

17.3 Age of Gain

The findings from Chapter 6 show the number of correct responses made by non-dyslexics from mean age 7:8 years to 14:1 years (SA and CA controls) (see Appendix A, Tables A.7 and A.6 respectively). The results present an opportunity to observe the general trend (this research was not a longitudinal study) in improvement on accuracy and speed with age, and to make comparisons with the dyslexic age of most gain. The SA controls took part in the multiplication experiment only.

The non-dyslexics make particular gains in accuracy as follows. A comparison of the young and medium-age SA controls (Figure 6.7) showed that between 7:8 years and 8:9 years, particular progress was made on accuracy of response to multiplication questions. The dyslexics make similar progress between the age of 10:7 years and 12:7 years (see Appendix A, Tables A.1 and A.2 respectively) and thus approximately 3–4 years later than the non-dyslexics.

The results on speed of response are similar to those found on correctness for the age at which most progress is made. The SA controls make most progress on speed of responding from 7:8 years to 8:9 years whereas the age at which this is shown for the dyslexics is between 10:7 years and 12:7 years. Thus the improvement in speed occurs at different times for the two groups. This is approximately 3–4 years later for the dyslexics.

Fleischner et al. (1982) reported similar age differences in mathematics. The number of arithmetic basic fact computation questions attempted in a three-minute trial by learning disabled children in Grade 6 was similar to that of non-disabled children in Grade 3, who were potentially three years younger.

The age of particular gains in speed of performing simple mental addition was found to be around Grade 3 (mean age 9 years 4 months and standard deviation 4.6 months) by Ashcraft and Fierman (1982) who found that third grade was the 'transitional' age at which students moved from counting (a slower process) to more automatic retrieval of addition facts. Where third graders were using counting solutions their error rates were higher and their ability to judge the 'reasonableness' of an answer was less.

Perhaps the young dyslexics were responding in a similar manner – resorting to counting (see Chapter 15 on Additional Behaviour) and making unnoticed errors due to relatively little knowledge of arithmetic. The later age of gain for dyslexics found by this research may indicate that the transitional age from counting to retrieval is three to four years later than for non-dyslexics. The age of gain for the controls was several months earlier than those of the students in the American study but the latter study did not test students below Grade 3.

The dyslexic participants in this research came mostly from privileged backgrounds and received sympathetic support for their difficulties. It is possible that dyslexics in less favourable educational circumstances would not show the gains seen here or, if they did show an improvement, that this might occur at a later age.

These results reinforce the hypothesis of a maturational lag, which is discussed next.

17.4 Maturational Lag

The results presented here for the most part are compatible with maturational lag; however, there is a great deal of evidence from elsewhere (see the next section 17.5) to indicate that maturational lag is insufficient to account for all the results.

The results that appear to support the maturational lag hypothesis are presented first.

While performing less accurately and more slowly than the CA controls, the dyslexics were more accurate than the SA controls (except not significantly so for the 1× and 10×) and were also faster than the SA controls (except in the young age band on the 'Y_M' condition). This suggests a delay in the dyslexic performance rather than a deviance (for the results on the correctness and speed of the dyslexics and SA controls on multiplication, see Chapters 6 and 10 respectively). The age of gain shown in section 17.3 also indicates a delay in that the dyslexics made particular gains in their performance approximately 3–4 years after the controls. Nicolson and Fawcett (1994a) also found evidence for a 'delay' when dyslexic children were found to perform significantly slower and with more errors than age-matched controls on a selective choice reaction task, but were at the same level as reading-age matched controls.

A further example of a delay was found on special number combinations in multiplication (see section 6.6 on correctness). The 'YM' condition contained questions chosen because they did not involve any obvious algorithm. The results showed that on the 'YM' condition the young and medium-age dyslexics performed no differently from the young and medium-age SA controls, whose mean ages were 3–4 years younger than the dyslexics; but by the time the difference between the mean ages of these two groups was nearly five years, the dyslexics were significantly better than the SA controls on the 'YM' condition.

The results indicate the presence of a learning lag on the part of the dyslexics.

Brown and Loosemore (1994) explain that dyslexics who 'progress through the same stages as non-dyslexics' are showing a delay when they progress at a slower rate. Indeed, within this mathematical research, there were several findings which showed that the dyslexics performed 'in the same way' as the controls.

The operations that were most accurate, the fastest and slowest were the same for the dyslexics and the non-dyslexics providing an example of the homogeneity of order between the two experimental groups. There was a strong and positive correlation on the order of difficulty of the tables and categories between the dyslexics and controls. Thus where a table or category was hard for the controls, it was also hard for the dyslexics. An important point is to be made here: the performance of the controls served as a gauge as to when it would be extra hard for the dyslexics, for example 11 × 12 and/or 12 × 11 was the hardest question for the young CA controls to answer in terms of speed (mean response time 16.77 seconds). The dyslexics also found this question the hardest (mean response time of 21.89 seconds) and also took longer to respond. Thus if a task was difficult for controls it was likely to be *extra* difficult for the dyslexics (Turner Ellis et al., 1996). Thus the relative difficulty of the mathematical questions was mainly similar for the dyslexics and controls. The dyslexics were not acting as a 'breed apart' on these mathematical tasks – there was an element of 'sameness' about their performance despite it being slower and less accurate.

The dyslexics 'shadowed' the performance of the CA controls, for example, in Figure 10.11 (Chapter 10), which shows the differences between the young and medium age band mean response times. The SA controls also 'shadowed' the dyslexics in Figure 6.2 (Chapter 6) on the number of correct responses on each multiplication table in the young age band. The 'shadowing' group comprised those whose results resembled the shadowed group but who were slower or less accurate, thus creating a shadowing effect when illustrated in a diagram.

The topographical terrains enabled a visual study of the speed of response across the tasks within an operation and also illustrated another way in which the performance of the dyslexics was the 'same' as the controls. Direct comparisons were made within and between groups. Overall the dyslexics were not too dissimilar from the controls in what they found difficult. The medium-age controls had peaks in the same areas as the medium-age dyslexics but at lower altitudes. Both groups in the old age band had 'peaks' on the same questions (48 ÷ 6, 96 ÷ 8, 108 ÷ 12, 84 ÷ 12 and 96 ÷ 12). The speed of responses given by the dyslexics closely resembled that of the controls in the next youngest age band, particularly on multiplication.

Overall the relationship between the dyslexic and control performance was remarkably consistent across the four operations, between the three age bands and for both speed and accuracy, adding to the confidence in the findings. The groups responded in similar ways, for example multiplication had the quickest response time of all the operations for both groups. Subtraction was the slowest operation for both groups.

Fleischner et al. (1982) proposed the possibility of a 'delay' when Learning Disabled children in Grade 3 performed basic fact problems in addition and subtraction. They wrote of a delay in reaching the stage of accuracy in computation and speculated that this might be a reflection of the 'children's inability to grasp number concepts at the ages when non-disabled children did'.

Maturational lag does not signify a structural defect, deficiency or loss. Potential is not necessarily limited and maturation may speed up, but unevenly so (Critchley, 1970). From this standpoint, the mathematical progress of the dyslexics would be expected to improve over time with continued learning. The medium-age dyslexics showed such progress both in accuracy and speed but the old dyslexics did not maintain this rate of advance, unlike the controls. It would have been interesting to include adult males of different ages – dyslexics and matched controls – in this study in order to follow the delay hypothesis across a longer time span. Forty-eight dyslexic adults, aged between 19 and 59, were assessed on two mathematical sub-items of the Bangor Dyslexia Test (Miles, 1982, 1997). On the Subtraction sub-test 21 'pluses' and 9 'zeros' were recorded and 33 'pluses' and 7 'zeros' were recorded on the Tables sub-test. Thus there is an indication that the difficulties experienced by younger dyslexics persist into adulthood (Miles, 1993). It is noteworthy that only 8 out of the 48 adults assessed scored a 'minus' on the Tables sub-item.

While maturational lag or some sort of delay does not explain all of the results, it is tempting to speculate that part of these results support the 'maturational lag' hypothesis. However, it has been established that dyslexics perform worse than non-dyslexics matched on reading or spelling age on *some* tasks (Turner Ellis et al., 1996).

The performance of the dyslexics on some mathematical tasks was not necessarily consistent with a maturational lag hypothesis. These are discussed next.

17.5 Performance Anomalies

Despite appearing to account for much of the data in the present research, maturational lag doesn't account for all findings (Ellis and Miles, 1977; Nicolson and Fawcett, 1994a, 1994b; Nicolson and Fawcett, 1995). This section details instances where dyslexics have shown particular difficulties that cannot be explained by a maturational lag hypothesis.

17.5.1 Progress on Accuracy

Although, in general, the dyslexics were more accurate than the SA controls there were some instances where this was not so. The dyslexics were significantly more correct than the SA controls (age bands combined) on all multiplication tables except 1× and 10×. A study of the age band performance for these two groups showed that the dyslexics were more accurate on these two tables in the young age band but the SA controls were more accurate on these tables in the medium and old age bands.

The dyslexics in the young age band were nearly three years older than the young SA controls that had a mean age of 7:8 years. Children of this age are new to the concept of multiplying by 1 and 10 in school. Hence they made 53 and 72 errors out of 240 on the 1× and 10× consecutively. This was in contrast to 18 and 40 errors made by the dyslexics on the 1× and 10× consecutively. The accuracy score for the dyslexics on these tables did not show the steady progress through the age bands made by the SA controls, and thus the SA controls scored more accurately than the dyslexics in the two older age bands. This accounts for the non-significant score in Table 6.3 on the 1× and 10× tables. Therefore the dyslexics aged from 11 years 5 months and upwards made more errors on these two tables than the controls that were approximately four years younger than them. These were on tasks that we would have expected the dyslexics to have mastered or learned well. Nicolson et al. (1999) found error rates in dyslexic adults even on tasks that had been overlearned. Nicolson and Fawcett (2000b) reported similar results on a Pacman task where the dyslexic children made significantly more errors than controls, even after extensive practice.

While speed improved across the age bands, this was not so on accuracy for the dyslexics. The Connectionist Model proposed by Browne and Loosemore (1994) on word spelling showed that the 'dyslexic' version of the model would learn more slowly and 'never achieve' the same accuracy level as the non-dyslexic versions. A study of accuracy on counting tasks was made on Mathematically Disabled/Reading Disabled (MD/RD) children. It was found that many of these children were unable to retain 'error notation' in working memory when monitoring was required during the counting process (Geary et al., 1999). Unlike the present research, a trend for greater accuracy with age was found by Fleischner et al. (1982) by both Learning Disabled and 'non-handicapped' children on basic fact problems in addition, subtraction and multiplication, but the participants in this study were younger and a high percentage of responses to the mathematical problems were correct.

17.5.2 Dyslexics Can Perform Worse than Reading or Spelling Matched Controls

Ellis and Miles (1977) compared dyslexics of average age 12 years 6 months with non-dyslexics matched on spelling age (average age 8 years 6 months), on correctly recalling arrays of digits that were visually presented. The dyslexics needed more time to respond than the non-dyslexics.

Dyslexic children performed more slowly than reading age controls on lexical decisions for words (deciding if a spoken word was real or nonsense) using "by-item" analysis (Nicolson and Fawcett (1994a).

Nicolson and Fawcett (1995) found that dyslexics matched with reading age controls performed more poorly on a wide range of tasks including blindfold balance, segmentation of phonemes, phoneme discrimination, letter naming speed, bead threading, rhyming and articulation rate.

17.5.3 Algorithms

This section refers mostly to multiplication.

In the present research an interesting discovery was made when comparing the correctness of the SA controls and the dyslexics on the 'X_M' and 'Y_M' type conditions in the Multiplication experiment. The young dyslexics were found to be differentially better on the 'X_M' condition compared to the 'Y_M' condition than the young SA controls. Thus where multiplication questions included tables with obvious algorithms the young dyslexics were significantly more accurate on these questions than on those with no obvious algorithm, compared to SA controls. By this age the dyslexics had learned few multiplication number facts, but the ones that they did know were those from tables that had a pattern. The dyslexics relied on this pattern more than the SA controls did to give correct answers. Thus the results gave an indication that the dyslexics had difficulty in memorising multiplication number facts that did not involve algorithms.

A further discovery was made when comparing the speed of the SA controls and the dyslexics on the 'YM' condition. The young dyslexics had a median time of 14.15 seconds compared to 8.34 seconds for the young SA controls. The SA controls were thus significantly faster ($p < 0.001$) than the young dyslexics on this condition. Thus dyslexics who are 3–4 years older than SA controls are performing more slowly on multiplication questions that do not involve algorithms. This represents a specific instance in which the dyslexics are at a disadvantage. Multiplication number facts that do not have algorithms are a particular challenge for young dyslexics to learn and, if this group is typical, then it is possible to make this generalisation to all dyslexics of this age. They are less successful at learning these facts through memorisation.

While the young dyslexics were able to perform as accurately as the SA controls who were 3–4 years younger than them on the 'YM' condition, they were significantly slower in producing their responses.

Possible explanations for these findings are as follows:

(1) The speed with which the dyslexics worked out the answer was slower than that of children who are about 3–4 years younger. Perhaps the 'counting/calculating speed' was slower since the dyslexics may have counted up 'in ones' to reach the final solution (Pritchard et al., 1989). It is known from the reaction time tests that reading the question and keying in the answer accounted for minimal differences between the groups and thus any differences found were not a consequence of poorer reading speed or motor response on the part of the dyslexics. Groen and Parkman (1972) studied a number of models showing how children solved single-digit addition problems. They wrote that where a person was unable to retrieve an answer they would then rely on a reconstructive algorithm to then work out the answer. The model that most adequately explained the children's response latencies was where the addition operation was performed by taking the maximum of the two numbers to be added, and then adding the lesser number

in increments of one, to the larger number. This is known as the 'minimum strategy'.

(2) Where the young dyslexics knew the answer they were delayed in responding. This could have been due to:

  (a) not immediately recognising that they knew the answer to a sum perhaps due to perseveration interference from the previous question or because they needed extra time to process the question;
  (b) not arriving at a quick decision as to how to respond. The Reading/Key Search Reaction Time Test timed the speed with which the participants read a number and keyed it in on the numeric keypad. The time taken to process the question, in terms of knowing the answer or not was a new feature in the main experiments. Perhaps the dyslexics were slower at deciding upon their response.

Overall it is possible to hypothesise that there is some inherent slowness in dyslexics that isn't all that susceptible to improvement. This is compatible with the findings of Nicolson and Fawcett (1995).

Miles et al. (2001) found that there were thirteen items on a Friendly Maths Test that were relatively hard for the dyslexics to answer. On these the difference in pass rate was 20% between the dyslexics and normal achievers in favour of the latter. These questions required the following skills: subtraction with borrowing, long multiplication, long division, supplying the missing number in multiplication and division sums, equivalent fractions (with the need to know multiplication/division facts) and an appreciation of the size of numbers. Thus the results gave an indication that the dyslexics had difficulty on questions requiring the use of number facts and their application in more complex procedures for problem-solving.

This research, like that of Pritchard et al. (1989), also found that dyslexics had fewer number facts at their disposal than non-dyslexics. The findings in both cases showed that dyslexics make more use of patterning than controls. Where tables follow a pattern they differ from other tables because of their regularity, as in the case of 2×, 5×, 10×. Additionally these tables are often taught earlier, enabling familiarity and experience to develop over a longer length of time than for the other tables.

17.5.4 The Ten Barrier

This section refers mostly to addition and subtraction.

No significant difference was found between the groups when comparing low with high addends, but not crossing/crossing the ten barrier (condition N versus C) was significant ($p < 0.001$), therefore crossing the ten barrier imposed an extra load on the dyslexics that slowed them down (see Chapter 12). A ratio of difficulty was ascertained comparing group performance in each age band. This favoured the NC over the high/low condition as having the main effect on the dyslexics in each age band. The ratio of difficulty was: 1 (LH) : 5.25 (NC) when comparing the young dyslexics to the young controls, 1 (LH) : 2.23 (NC) between the groups in the medium-age band and 1 (LH) : 1.5 (NC) when comparing the old dyslexics to the old controls.

Therefore dyslexics are at risk particularly on addition questions that involve crossing the ten barrier. Possible reasons for this are as follows:

(1) The ten barrier requires the need for extra resources to be allocated to reach an answer. Nicolson and Fawcett (1990) found that the balancing skill of dyslexics was adversely affected by a secondary task that distracted their attention from it. The dyslexics needed to channel a large part of their available resources to the primary task of balancing, in order to consciously compensate for their difficulty. Brown and Loosemore (1994) use a connectionist model to show how poor reading can be explained in terms of a limitation in available resources, causing learning to take place more slowly with a lower level of accuracy achievable. Thus when insufficient resources are allocated to a task the outcome is a lower level of performance.

(2) Extra resources may be in the form of an increased need for memory demand, which the dyslexics find harder than controls to achieve. Hitch (1978) wrote of

the effects of carrying within mental addition. As a result an extra computational stage was created where the carry digit was held in working storage and this helped to form the initial information needed to then add for the next decade.

(3) Both the units and the tens in the sum need to be adjusted and remembered before the answer can be typed in. Hitch (1978) reported that the time to perform mental addition, by adults, increased through four types of problems: no carrying, carrying in the tens, carrying in the hundreds and carrying in both tens and hundreds, thereby reaching the conclusion that carrying is a separate stage that takes up extra time.

(4) Dyslexics have greater difficulty at multitasking within mathematics, which the ten barrier provides, like the results reported by Nicholson and Fawcett (1995) on the dual task balance test. The ten barrier provides one extra dimension to the task which tips the balance for the dyslexics. Compare this to the addition and subtraction of high/low addends/subtrahends. Where all else fails, the participant can count in ones backwards or forwards sequentially. The ten barrier, in contrast forces the participant to consider and adjust two place values.

(5) When counting within a 'ten' and therefore not crossing the ten barrier, this is quicker than having to begin counting in one ten and switching to another ten. Articulation rate is therefore crucial when under timed conditions. The articulation rate of dyslexics is thus adversely affected by the additional change to the tens value in comparison to the controls. Each 'ten' value from twenty through to ninety involves the articulation of two syllables whereas the 'units' involve numbers of only one syllable, except 'seven' which has two syllables. This alone would explain the increased difficulty of crossing the ten barrier over high/low addends/subtrahends which include a change in only the 'units' value potentially. (See section 17.8 for a discussion on articulation.)

(6) There is lack of appreciation of the conventional decimal number system requiring grouping by tens. Dyslexics made up to 40% more errors than

age-matched controls on addition of two 2-digits with carrying (Joffe, 1983). This poor performance was also attributable to the need for re-labelling or re-naming of the units and tens.

17.5.5 Instantaneous Responses

For the purposes of this research an 'instantaneous' response was defined as one which occurred between 0 and 1.99 seconds. The results revealed overall that the dyslexics were not able to respond as instantaneously as non-dyslexics. As with other findings, the young dyslexics were consistently poorer in their performance in comparison to non-dyslexics, and within the fastest time (0–1.99 seconds) the gap in number of responses between the groups widened with increasing age, exemplifying an unexpected age difference (see section 17.7). The general trend showed that the performance of the dyslexics resembled that of the controls who were approximately two years younger.

A number of possible reasons for these results are as follows:

(1) The dyslexics were slower at processing the question and arriving at an answer. The Key Search Reaction Time Test showed that the time taken by dyslexics to read one- and two-digit numbers and type them in on the number pad was minimally different from the controls when compared to the overall response times on the four operations. But the experimental questions themselves required the participant to think about the meaning of what they were being asked: to operate on the numbers according to the sign – in contrast to typing a number seen, as in the Key Search Reaction Time Test. In addition an answer had to be found as quickly as possible.

(2) The pressure of time led to increased stress, which affected performance. Dyslexics are particularly prone to lower their performance under the pressure of time.

(3) The dyslexics lacked confidence in their mathematical knowledge, in their answers, in remembering where they were in a calculation and in holding on to

the answer while searching for the keys to type it in. A number of hesitations on the part of the dyslexics may have decreased their chances of answering questions as swiftly as the controls because they were more apprehensive.

(4) They found it difficult to maintain a continual level of performance over time on naming tasks (Fawcett and Nicolson, 1996 – naming sub-item in the Dyslexia Screening Test) and thus they may have performed worse than normal on questions that in isolation they could have answered more quickly.

(5) The dyslexics found it difficult to optimise both speed and accuracy. In order to go as fast as possible while making as few errors as possible, some mechanism is required to detect the optimum response time above which errors occur, thereby maintaining a 'safe' rate for responding (Rabbitt, 1979). That dyslexics have time estimation difficulties (Nicolson et al., 1995) will have an adverse impact on the attempt to maintain a 'safe' response time, due to 'overshooting' or 'undershooting' the time.

(6) What constitutes an instantaneous response for the controls was not of the same time span as that for the dyslexics. The controls made more responses than the dyslexics the older the age band in the time 0–1.99 seconds and the gap between the groups on number of responses decreased with age in the range 2–3.99 seconds. This indicates that a fairer instantaneous time for the controls was 0–1.99 seconds while for the dyslexics it was 2–3.99 seconds.

(7) The dyslexics were less able to perform mathematical operations at speed due to an inherent difficulty with mathematics; connected to their lack of memory for number combinations (multiplication and division number facts, number bonds to ten) that would have speeded up their performance. In contrast the mathematical memory of the controls enabled them to form more mental anchor points, which they utilised to give their answers more quickly.

(8) The young dyslexics had not absorbed the interrelationship between numbers at the same pace as non-dyslexics in the classroom. Hence they would not have noticed all the number patterns that the controls had. They may have

become disheartened at their lack of memory for number facts, seeing their counterparts accelerating past them in class, and completing assignments and responding to teacher questions with greater accuracy, enthusiasm and speed. Thus when met with the mathematical questions that this research presented, the young dyslexics had less stored knowledge to draw upon in relation to the controls. Thus acquisition of number fact is reduced for dyslexics in that they are slow to pick up the familiar.

(9) The dyslexics had a slower pace of calculation; affected by delayed onset of calculation due to slow uptake of the question, slower counting rate, slower articulation of the numbers and a slower initiating response in moving the arm as a first step in reaching for the number pad to type in their answer.

(10) While all participants were aware of being timed, the controls treated this aspect of the experiment more realistically than the dyslexics, who are well known generally for having a poor sense of timing (Nicolson et al., 1995). An interesting project for the future would be a study of the time estimation skills of dyslexics over greater periods of elapsed time (for example, 30 seconds, several minutes or hours) and comparing a range of ages including adults (Miles (1993) writes of the persistence of dyslexic difficulties into adulthood).

(11) Dyslexics lacked automaticity of response due to difficulties with paired associate learning. Thus there was a delay in the learning stage of mathematical number facts. An interesting question is whether the dyslexics would ever have been able to perform as instantaneously as non-dyslexics at an older age or under different educational circumstances. The answer is potentially 'no'. An explanation in terms of a delay is therefore implausible. Therefore the results can be thought of in terms of a deficit – whence a physical difference in the dyslexic brain, perhaps in the cerebellum (Nicolson et al, 1999), is a causal factor in dyslexics being less able to respond as instantaneously as non-dyslexics on mathematical questions involving the four operations.

Some dyslexics have a magnocellular defect shown by their difficulty on tasks that require rapid visual processing. On inspection, there was less organisation in the magnocellular layers of the dyslexic brains and smaller cell bodies (Livingstone et al., 1991). But Nicolson et al. (1999) discovered that the visual magnocellular system could not have contributed to brain activation differences between the dyslexics and the controls (using positron emission tomography) during a motor learning task, because the task had been undertaken with eyes closed. Indeed Stein (2001) reported that there are magno (large) cells in all the motor and sensory systems that specialise in temporal processing and that the cerebellum may be considered as the main part of the magnocellular timing system within the brain.

A deficit in rapid temporal processing does not explain why dyslexics continue to make accuracy errors even after extensive practice. In contrast a cerebellar deficit can take account of these findings (Nicolson and Fawcett, 2000b). See section 17.8 for a further discussion on the additional behaviour of the participants in this research and the link with behavioural deficiencies that are caused by the cerebellum.

The dyslexics were most able to respond instantaneously on multiplication of the four operations. The results for the controls were similar but for a preference for division as the operation with the most number of instantaneous responses in under 2 seconds. Perhaps the controls had faster mechanisms for recognising facts that they knew and could utilise this skill in division. For example, 72 ÷ 8 could have been a fact that they had learnt without resorting to transposing the question into the multiplication number fact, '8 times what is 72?' Thus the controls may have had many more actual 'division' facts at their disposal as opposed to transposed multiplication facts. The reason for the dyslexics preferring multiplication to division may have been due to their reliance on transposed multiplication facts to see them through the division questions. An example of this is given by a dyslexic participant D3 who verbalised '33 ÷ 3, how many 3s in 30?'

It is of interest to consider why subtraction should have elicited the least number of instantaneous responses by both groups. This may be explained by their reliance on an internal number line with a natural preference for ordered incremental steps along it. Subtraction involved moving backwards along the number line, and since we are more familiar with saying numbers forwards rather than backwards, more resources are needed for the less usual tasks. This is rather like our ability to say the alphabet more fluently and accurately in the forward direction as opposed to in reverse. Thus we are more familiar with counting forwards. Indeed, many of the subtraction questions may have been translated into addition questions; for example, on questions in the LN and HN categories: 58 – 6 could have been construed as 6 + $\underline{2}$ = 8 and thus the answer is 5$\underline{2}$. Examples of dyslexics turning a subtraction question into an addition sum is given by participant D14 who worked out 51 – 28 by adding 28 + 2 = 30 then adding 20 and then 1, and participant D30 who worked out 92 – 47 by '47 + 3 = 50, 30 up to 90, then add 2'.

Therefore the issue of transposition comes into question. Perhaps the dyslexic participants are adept at using the strategy of transposition from one operation to another or from an anchor point to an unknown fact, in the face of difficulty – a process fraught with accuracy and timing dangers. Transposition at least enables the dyslexics to use a strategy for arriving at an answer in the best way they know how in the circumstances.

Additionally there are some interesting results that deserve mention, as follows.

17.6 The Four Operations: Some Thoughts

17.6.1 Addition and Subtraction

The following abbreviations were used to represent the five addition/subtraction categories in the thesis:

LN – low addends/subtrahends that did not cross the ten barrier.
HN – high addends/subtrahends that did not cross the ten barrier.
LC – low addends/subtrahends that crossed the ten barrier.
HC – high addends/subtrahends that crossed the ten barrier.

HARD – addition/subtraction of a 2-digit number to/from another 2-digit number where the addend/subtrahend units were high (6, 7, 8). The resulting sums crossed the ten barrier with 'carrying'/'borrowing' respectively.

On addition and subtraction the young controls were significantly quicker than the dyslexics on all categories except for HARD on subtraction. The dyslexic mean response time was over 4 seconds slower than the controls on all categories except HARD (2.91 seconds). The reason for the lower level of significance on HARD was because the dyslexics decided to 'pass' these difficult questions relatively quickly. The speed of the dyslexics' decision may have been hastened by the fact that HARD questions were distinguishable from other categories because two pairs of two digits were presented on the screen. On other categories the screen displayed two digits, then the sign followed by a single digit.

On subtraction the HN category elicited faster mean response times than the LN category for all groups (except in the case of the medium-age controls). One possible explanation might be the way in which the sum was worked out. The HN questions had high numbers in the unit's position, for example $4\underline{8} - \underline{6}$, and a quick way to solve these types of questions could have been to count on (add) from the subtrahend up to the number in the unit's position. The distance is less numerically than that found in the LN type questions, for example 29 – 2, where the numerical distance is 7. If counting was taking place, the greater the numerical distance the greater the time taken to count. Groen and Parkman (1972) state that the greater the number of times that a counter is incremented the longer is the mean reaction time. Thus it appears that the participants used complementary addition (Williams and Shuard, 2001) in which case $4\underline{8} - \underline{6}$ was thought of as, 'What must be added to 6 to make it 8?' Williams and Shuard (2001) comment that, 'Subtraction is only fully understood when it is seen as an aspect of addition'. Thus in this sense the groups, including the young dyslexics, appeared to have conceptually grasped the interrelationship between addition and subtraction.

Subtraction was the slowest operation for both groups. It is harder to count backwards than to calculate by counting forwards one by one. One possible reason for this is that we are more familiar with counting forwards and have done so many more times than in the reverse order. Perhaps, as indicated above, the participants thought of the subtraction question in terms of complementary addition, thus translating the sum into a different operation, thereby creating an extra stage and taking longer.

17.6.2 Multiplication and Division

Multiplication had the quickest response time of all the operations for both groups. Multiplication number facts are explicitly taught at school so ideally they can be reproduced automatically without the need to resort to calculation; hence the increased speed of execution in these results in comparison to the other operations. The expected number of known multiplication facts is finite (multiplication of whole numbers from 1×1 to 12×12) in comparison to the wider range of number facts needed to answer the addition and subtraction questions.

The accuracy of response on division was a particular challenge for the dyslexics (it was the least accurately answered operation) due, in part, to the way the division question was expressed. The dividend acted as the largest number in the question and the numerical value between it and the divisor was far larger generally than the numerical value between the multiplicand and the multiplier in multiplication. This potentially caused a delay in the recognition of the answer and/or the onset of calculation or memory retrieval.

Division number facts may be stored in multiplication mode; for example, $42 \div 7$ may need to be manipulated to read '7 times what equals 42?' for the question to be understood. A search for an anchor point would have been harder to find since these would have been stored in multiplication mode and translating from multiplication to division would take up extra memory resources. It is well known that dyslexics have particular difficulty in translation, for example when learning another language or decoding musical notation (Miles and Westcombe, 2001). When translation takes place there is a reduced memory span due to a translation/storage interaction taking place in working memory (Ellis and Hennelly, 1980). Cipolotti and de Lacy Costello (1995) consider that we do not have individual representations of division facts, but instead translate the division problems into multiplication mode and retrieve stored multiplication facts instead.

Dyslexics are less likely to learn their multiplication number facts because they tend to fluctuate in their 'referents' (Miles and Ellis, 1981) thus not 'tagging on' to the same aspects of a multiplication sum when presented on separate occasions, for example: $6 \times 4 = 24$ or $4 \times 6 = 24$ and $2 \times 12 = 24$ or $12 \times 2 = 24$ and $3 \times 8 = 24$ or $8 \times 3 = 24$, where there is the same outcome in all cases, but it has been arrived at from different directions. With such an array it is hard for the dyslexic to build up the relationships between number facts which help to make them memorable.

17.6.3 Anchor Points

The medium-age dyslexics were as accurate as the controls on all operations within tasks. One explanation could be that these participants had received specialist input including extra practice at those aspects of mathematics that they found to be a challenge. It is likely the older dyslexic has had more opportunity to understand the interrelationship between numbers and possesses a greater range of number facts which act as 'anchor points'. An anchor point is a known number fact, from which other number facts are derived. As the number of anchor points increases, the more versatile the participant is in answering unknown questions sited near these anchor points. Thus the medium-age dyslexics were able to answer with more accuracy than the younger dyslexics who had less knowledge at their disposal. An example of 'anchor point' usage was given by a dyslexic participant D12 (on multiplication) as follows: 'Nothing came [into my head] and then I remembered $9 \times 9 = 81$ and subtracted' to find the answer. 'Anchor points' are commonly used by dyslexics in the researcher's own experience of working with dyslexics on mathematics.

The performance of the old dyslexics in comparison to both the dyslexic group themselves and the controls has led to the discovery of an unexpected age difference in mathematics.

17.7 Unexpected Age Difference (UAD)

One of the most interesting findings was that of an Unexpected Age Difference (UAD) between the medium-age and old dyslexics. The general trend for the controls was an improvement in speed and accuracy with age whereas this trend was not so pronounced for the dyslexics. No significant improvement in performance was made between the medium-age and old dyslexics on the following: multiplication (correctness), division (speed, correctness), addition (speed, correctness) and subtraction (speed, correctness).

The medium-age dyslexics performed better than the old dyslexics on: 1×, 3×, 5× (correctness), ÷8 (correctness), ÷1, ÷6, ÷8 (speed), HN, HARD (addition correct), HARD (addition speed) and LN, HN, HC (subtraction correct). The results for correctness on subtraction also indicated that the old dyslexics were not making the expected progress with age as found generally for the control group. The medium-age dyslexics were significantly more accurate than the young dyslexics on the LN and HC categories, whereas this difference was not significant between the young dyslexics and the old dyslexics.

Not only were the oldest dyslexic group showing a UAD within their own dyslexic population, but also when compared to the non-dyslexic group. The old controls were significantly more accurate than the old dyslexics overall ($p < 0.05$) on division as well as addition ($p < 0.01$) and marginally so on subtraction ($p < 0.06$). Differences were found between the groups on HN and LC for addition and HC for subtraction. The difference between the old dyslexics and old controls was greater than that generally found between the two experimental groups in the medium-age band.

There are a number of possible reasons for the UAD:

(1) Weakness at paired associate learning (Done and Miles, 1978) whereby the old dyslexics had not rehearsed their number facts as often as the medium-age dyslexics and thus associations once made had been lost and needed revisiting to maintain the previous level of association. For mathematical memory to function as efficiently as the controls, the dyslexics needed to practise their number facts more often and over a greater number of years and therefore had not done so adequately in the old age band. Educators may have assumed that dyslexic students knew their number facts by this age and thereby placed less emphasis on continued revision of what could be regarded as basic facts.

(2) Changes had taken place in the developing dyslexic brain that affected the speed of processing of mathematical questions on the four operations in the old age band, changes potentially pertaining to adolescence.

(3) Interference effects where the old dyslexics paused to consider the interrelationships between numbers in their quest for assimilation of numerical construct. Perseveration effects acting as interference – where the dyslexic participant was considering an answer to a previous question, which had the effect of slowing their rate and accuracy of response to the present question.

(4) Slower decision-making – linked to point 3. In a study of reaction times, Nicolson and Fawcett (1994a) found that dyslexics aged 11 and 15 years performed significantly slower and with less accuracy than their age-matched controls on a selective choice reaction task. The researchers suggested two possibilities: that the dyslexics took longer to classify the stimulus or the 'central executive' took longer to make the appropriate decision. The 'central executive' acted as a 'supervisory controlling system' in working memory (Baddeley, 1986).

(5) The 'Matthew' effect (Stanovich, 1986) – the title of which is taken from the Gospel according to Matthew: 'For unto everyone that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath' (XXV: 29). The 'Matthew' effect can explain the findings. In the case of the controls, a cumulative effect of ease of acquisition of number facts and their frequent usage leads to more expertise, confidence, a larger mathematical knowledge base, greater understanding of the interrelationship between numbers and awareness of patterns within the number facts, leading to acquisition of 'even greater expertise at a faster rate' (Stanovich, 1986). For the dyslexics – a cumulative effect of difficulty of acquisition, later age of gain, lack of practice of number facts as well as memory difficulties exacerbated by stress and pressure particularly felt between 12 and 14 years of age can lead to an Unexpected Age Difference. Miles and Varma (1995) present accounts of stress shown by dyslexics.

(6) Lack of cognitive resources – Nicolson and Fawcett (1990) found that 13-year-old dyslexics performed as well as same aged controls on a beam balance task but their performance became significantly worse when they were asked to count backwards at the same time. Thus when the dyslexics performed a dual-task it was possible that they had needed to 'invest significant conscious resources for monitoring balance'. Their 'conscious compensation' explained why the dyslexics had performed more poorly on a task that, on its own, had been successful, whereas fewer resources had been available in the dual-task condition. In the light of these findings, the old dyslexics in this research had fewer resources available for answering the questions. Brown and Loosemore, (1994) used a 'connectionist' model to show how dyslexic children allocate 'fewer processing resources to the learning process' for spelling where limited computational resources were available. Thinking of words in terms of letter-sound correspondence they developed the concept of 'friends' whereby a word such as 'hill' has 'friends' such as 'will' and 'till' which showed regularity. Likewise, in this research, regular multiplication and division tables as well as 'anchor points' (see section 17.6.3) could be referred to as 'friends'. A UAD could be explained in terms of 'anchor points' or 'friends' being lost from the medium-age to the old age band, perhaps because of lack of rehearsal – because of this they could not be utilised as before.

(7) Cerebellar dysfunction in dyslexics, leading to lack of automaticity on tasks requiring rapid processing and multitasking – especially evident in a rote learning situation (Fawcett and Nicolson, 2001). The cerebellar deficit hypothesis predicts that dyslexics will perform more poorly than controls on well-learned skills (Nicolson and Fawcett, 2000b). Mathematical automaticity appeared to decline between the medium-age and the old age band for dyslexics, indicating that the dyslexics had not completely automatised their mathematical skills in this research. Ashcraft and Fierman (1982) showed enthusiasm for the notion of increasing automaticity with age through to adulthood as a natural phenomenon in mental arithmetic processing, but their research was not concerned with dyslexics.

(8) The speed of internal vocalisation changes as a direct result of the adolescent male voice breaking. This is likely to have taken place from the medium-age to the old age band. Thus articulation rate of the mathematical problems and their resolution is adversely affected for the adolescent dyslexic (see section 17.8 for a discussion on articulation rate).

(9) Memory difficulties – Plato's theory of memory as a wax tablet serves as an analogy of why dyslexics don't remember well (Plato, Theaetetus – see the translation by Cornford, 1935). Plato likens memory to a wax tablet where what is to be remembered leaves an accurate and lasting impression in a waxen block (memory). Plato writes of a conversation between Socrates and Theaetetus (who made important discoveries in mathematics), which may have taken place around 369BC. Socrates speaks:

> Imagine…that our minds contain a block of wax, which in this or that individual may be larger or smaller, and is composed of wax that is comparatively pure or muddy, and harder in some, softer in others, and sometimes of just the right consistency . . . whenever we wish to remember something we see or hear or conceive in our minds, we hold this wax under the perceptions or ideas and imprint them on it as we might stamp the impression of a seal-ring. Whatever is so imprinted we remember and know so long as the image remains; whatever is rubbed out or has not succeeded in leaving an impression we have forgotten and do not know.

In this way, Plato brings to mind a number of interpretations of the state of the waxen block as an analogy of the dyslexic's memory. The wax may have been soft in youth and so impressions of number facts and number patterns melted and became 'blurred' and were therefore forgotten. Once forged a few years later, memory for number facts then declined, perhaps due to the changing circumstances of puberty and lack of use – fresh imprints of other knowledge being printed over the top of other impressions – this would explain the perseveration and interchanging of numbers, especially when in a hurry. As a consequence of this way of thinking, it is important to consider how possible it is to play a part in the condition of the wax, during the learning of number facts and use of mental calculation.

In a study of mental addition in third, fourth and sixth graders, Ashcraft and Fierman (1982) indicated that we have a mental representation of addition facts that are retrieved from some sort of memory structure which stores this mathematical information in an organised way, which is accessible by memory search processes that can locate and retrieve the information. Steeves (1983) investigated why dyslexics aged 10 to 14 years did not perform as well as their non-dyslexic counterparts despite having the same abstract reasoning ability, logical thinking and mathematical potential. These children performed significantly lower on computational efficiency as a result of 'inferior memory skills'. The dyslexics were found to be deficient on only some facets of memory: 'logical memory, memory span (both forward and backward), and easy and hard tests of associate learning'. These were subtests of the Wechsler Memory Scale. Steeves stressed that computational ability was a learned skill rather than an inherent gift and she concluded that the memory skills of both gifted and average dyslexic children were 'inferior to those of non-dyslexic children'.

Adams and Hitch (1997) argued that mental arithmetic with written numbers (as in the present research) was a task that loads working memory. They concluded that their results 'suggest that working memory is an important general-purpose resource supporting schoolchildren's mental arithmetic performance'. Working memory is defined as 'the limited capacity system responsible for transforming and maintaining temporary information' (McLean and Hitch (1999).

Geary (1993) states that the combination of working-memory difficulties and the tendency to commit computational errors during the learning stage contributes to poorer fact retrieval and errors when attempting to represent and retrieve arithmetic facts from long-term memory. This reinforces the 'Matthew' effect stated by Stanovich (1986). Where there is slower counting speed or rate of articulation of the question and any working out, the less that the working memory can retain. Where counting or working out has occurred, the answer 'might not become strongly associated with the problem' leading to a weaker representation of the arithmetic fact in long-term memory.

Additionally, a child who makes computational errors is more likely to retrieve incorrect answers on subsequent attempts (Geary et al, 2000). Errors won't be modified or improved upon if the child is unaware of them.

Long-term memory is a system that relies on semantic coding of information (Hulme et al., 1991). The UAD shown by the old dyslexics in the present research indicates that they had difficulty retaining the mathematical facts in their long-term memory. A reason for this could be that number facts hold very little meaning and therefore cannot be semantically processed and stored – a process which is often adopted by dyslexics to circumvent their difficulties.

(10) A lexical encoding deficiency – Done and Miles (1978) found that dyslexic children performed less accurately than controls in immediate memory for visual material when naming was required (naming digits). 'Dyslexics are deficient in making available the language (lexical) equivalents of visual stimuli' (Ellis and Miles, 1981). The short-term memory span for verbal material depends upon the efficiency of the associations formed between the lexical code and its articulatory representation (Miles and Ellis, 1981). When attempting to learn number facts, there is a deficiency in forming a lexical code and this, along with the normal decay rate, makes difficult the representation of both the number facts as well as any relationship between them, thus explaining why dyslexics have a weakness at arranging units in a required order, such as months of the year, seasons, recall of auditorily presented digits and multiplication tables (Miles and Ellis, 1981).

Whatever the mechanics of the dyslexic brain it is clear that memory problems 'seriously impede the progress of dyslexics in mathematics' (Miles et al., 2001). By way of compensation, dyslexics were observed making 'additional behaviours' while performing the mathematical tasks.

17.8 Additional Behaviour

The dyslexic participants appeared to be behaving overall in a different way to the controls during the experiments. This behaviour was noted and subsequently divided into four categories based on the type of responses observed: use of fingers as an aid to calculation, other bodily movement, audible vocalisation relating to the question and any other audible vocalisation. These were termed 'classified' behaviours and it was found that the dyslexics did show more of these overall than the controls.

We need to consider why the dyslexics should have behaved like this. Dyslexics often fidget with their hands when they are in a listening situation in class. Perhaps they have a need to occupy their hands or bodies in some form of movement.

There are a number of possible reasons for these results:

(1) When dyslexics are in a stressful situation they tend to move more. Were these behaviours related to stress and therefore did the dyslexics make more of these behaviours on the most difficult operation (as found in the order of difficulty)? This was not the case. For example, the dyslexics were slowest on subtraction but the number of category behaviours was not highest on this operation. Thus dyslexics were not making more of these behaviours on the most difficult of tasks.

(2) Inhibitory factors are not as strong in the dyslexics as with the controls.

(3) Some of the available resources that the dyslexics have are spent on movement that acts as a distraction for the mathematical task in hand.

(4) The movements observed helped to stimulate the mathematical dyslexic brain. This was the dyslexic way of giving their all and in so doing, expending a larger amount of observable energy than the controls. Movement may have prevented the smooth learning of the number facts initially and the memory for them subsequently.

(5) Were the movements automatic where automaticity was not a skill in the mathematical tasks, thus leading to displaced automaticity?

(6) Frustration – dyslexics were aware that they were being asked questions that were a challenge and this presented itself in these behaviours.

(7) Comfort – these movements were performed to provide comfort and a feeling of well-being.

These behaviours were greatest in the young dyslexics but decreased with age. Perhaps this was a maturity factor where inhibitory processes were more powerful with age. The controls showed no such preference of movement in the younger age bands. There is something unique about the performance of dyslexics in the young age band that has been revealed in many instances through the research.

(1) ***Category A:*** *The use of fingers.* The dyslexics used their fingers as manipulatives in the calculation of multiplication to a greater extent than the controls ($p < 0.001$). Fingers were particularly useful on tables where algorithms were present such as 2× and 5×. Use of fingers took the place of the need for memorisation of the number facts. Miles (1993) reported the use of fingers by dyslexics when reciting their multiplication tables. A further study by Pritchard et al. (1989) showed that in order to do calculations the dyslexics tended to use their fingers as a way of compensating for their weakness in memorising number facts. There is regularity within the number system that dyslexics rely on; that 'numbers go up in ones'. Many dyslexics of all ages cannot count without some kind of concrete representation of the numbers that are being counted. By 'doing something with their bodies', such as using fingers, this could be an attempt to 'lighten the load of material which has to be lexically encoded' (Miles and Ellis, 1981). Butterworth (1999) writes of 'an intimate connection between representations of fingers and representations of numerosities in the parietal lobe' whereby if the normal development of finger representation fails to develop, number skills are adversely affected. A larger number of cells are dedicated to representing our fingers in the brain the more we use them. Thus the compensatory strategies of

dyslexics shape the way their brains are formed. Butterworth (1999) hypothesises that normal representation of numbers in the brain will not be achieved 'without the ability to attach number representations to the neural representations of fingers and hands in their normal locations'. Thus finger use plays a vital role in counting and arithmetical skill development.

(2) ***Category B:*** *Other bodily movement.* The dyslexics performed significantly more of this type of behaviour on all operations compared to the controls. This movement was not limited to a particular area of the body. Itching, rubbing, feeling, repetitive movement, leg jiggling, running fingers through hair and closing eyes to think were just a few of the observed behaviours in this category. This type of behaviour was most significantly different from that of the controls in division; the operation that the dyslexics were least accurate on. Did the difficulty of the task elicit more of this behaviour or did the behaviour cause less accuracy? This is not clear because more Category B behaviour was noted on multiplication and addition. Perhaps controls did not exhibit comparable Category B behaviour because their knowledge of division number facts was significantly better than the dyslexics; indeed division was their best operation for instantaneous responding in less than 2 seconds.

MacMeeken (1939) made observations of children with developmental aphasia who in today's terms would have been thought of as dyslexic. Emphasis was placed on the importance of observing 'how' tasks are performed. MacMeeken wrote of an 'outstanding feature' of word recognition difficulty: 'the intense effort made to sound, to blend, these letter units into the word. Such effort is in many cases accompanied by exaggerated tongue and lip movements, movements of the head, facial grimaces, even by other body movements, say, of arm or leg' (see Chapter 1). In this connection, Hermann (1956) conducted a series of comparative investigations into the symptoms of congenital word-blindness (a term for dyslexia) and Gerstmann's syndrome, which concluded that 'the fundamental disturbance in the two states is the same'. One example was given in the writing of numbers when dictated: For '1,548' both the Gerstmann patient and the word-blind person wrote 1000548. The chief manifestations of Gerstmann syndrome are: right–left confusion, problems with calculation and disorders of the body-schema such as finger agnosia, dysgraphia and deficiency in symbolic learning. Critchley (1970), Vellutino (1979) and Miles et al. (2001) also refer to this theory. In line with this is the claim by Karádi et al. (2001) that dyslexic children (mean age 9 years 2 months) have a spatial dysfunction illustrated by their weakness at mental rotation. Additionally Chochon et al. (1999) state that digit naming is often 'selectively preserved in "Gerstmann syndrome" patients with acalculia stemming from a left inferior parietal lesion and who experience severe difficulties in mental arithmetic'. Thus naming a digit (as in the Key Search Reaction Test in this research) did not necessarily access a 'semantic code' (Cipolotti and Butterworth, 1995) and therefore this might explain why the dyslexic participants performed relatively better on the Key Search Reaction Test than on questions regarding the four mathematical operations.

Miles et al. (2001) recognise the importance of these findings for our understanding of dyslexia and conclude that 'this whole area is a fascinating one and calls for systematic further research'.

It is of interest to speculate on the contribution of the cerebellum to these additional behaviours. While the cerebellum is known to enable motor tasks to become automatic (Nicolson et al., 1999; Fawcett and Nicolson, 2001), where the system is working close to its limits some gross signs of cerebellar dysfunction may appear in the form of additional uninhibited automatic behaviour masking as conscious compensation.

The idea of inhibitory difficulty causing the observed bodily movement is thought-provoking and deserves further research. Geary et al. (2000) found that those children with learning disabilities (on both mathematics and reading) had a 'high proportion of retrieval errors that were counting-string associates of one of the addends' on an addition strategy assessment. They concluded that these findings were synonymous with poor inhibition of irrelevant information. It may be that simple arithmetic processing is naturally prone to interference because of the large number of associations needing to be formed from a small number of basic symbols (Campbell and Graham, 1985; Ashcraft et al., 1992). Dehaene (1997) writes of young children who are 'unable to inhibit a spontaneous but incorrect tendency' when they impulsively choose the length of the row of objects to determine their response to which row has more, even though they are competent in number processing.

(3) ***Category C:*** *Audible vocalization relating to the question.* This behaviour is comparable to observing a child 'sounding out' as they are spelling or reading. A dyslexic who sounds out is attempting to make a link between the sound that they hear and the letter(s) that make that sound, thus finding the correct label. For some, the sound needs to be repeated several times before recall is achieved. The process is slow and needs active access. Some dyslexics needed to repeat the mathematical question out loud to decide if they knew the related number fact or not. It was as if they needed to gain access to what the question required through a route other than just quietly looking at the question. Miles and Ellis (1981) refer to input not having been 'registered' leading to a re-enactment. This is characterised by repetition of the question. Repetition or vocalising may have been a way to aid a weak memory for number facts – by talking the sum through this enabled the participant to retain the workings long enough to provide an answer.

The dyslexics made significantly more Category C behaviour than the controls on multiplication.

Fawcett and Nicolson (2001) state that 'our most complex motor skill is articulation' and where this is less fluent than normal, more conscious resources are used, thus depleting the remaining resources for use in processing. Cerebellar impairment is the cause of the lack of fluency. While speed of articulation was not specifically measured in this research, the greater use of vocalisation by the dyslexics is responsible for directing attention to the issue of articulation.

Denckla and Rudel (1976) showed that dyslexics were slower than non-dyslexics on tests of rapid repetitive naming of pictured objects, colours, letters and numbers. Done and Miles (1988) presented dyslexics with 65 pictures which had to be named as quickly as possible. A study of response latencies showed that the dyslexics were slower than the controls in producing the right names. Geary et al. (2000) found that first graders who were learning disabled in both mathematics and reading or just reading had slower familiar-word articulation speeds. Reading-disordered children showed speech production difficulties when naming pictured objects and when repeating both multisyllabic words and phrases (Catts, 1986). It was suggested that the reading disabled children were less able to perform the motor programmes of speech as accurately as normal children. Catts (1989) found that dyslexics repeated phrases significantly more slowly than normal subjects and made more errors in the production of complex phrases. Catts concluded that 'many reading disabled individuals have difficulties in producing speech sound sequences [due to] deficits in encoding phonological information as well as problems in planning and, perhaps, articulating phonologically complex sound sequences'.

Nicolson et al. (1999) proposed that detected cerebellar abnormalities lead to 'difficulties in acquisition and automatisation of elementary articulatory skills and auditory skills (and hence to difficulties in phonological processing)', and Fawcett and Nicolson (2001) showed that cerebellar impairment could be predicted to cause the 'phonological core deficit that has proved such a fruitful explanatory framework for dyslexia'.

Hitch and McAuley (1991) found that children aged 8 to 9 with arithmetical learning difficulties (children impaired on arithmetic with normal intelligence and normal reading attainment – termed ALD) tended to count more slowly and have lower auditory digit spans. It is possible that some of the ALD children in this study were dyslexic, for, according to Miles and Miles (1990), 'there is no contradiction in saying that a person is dyslexic while nevertheless being a competent reader'.

Baddeley et al. (1975) and Ellis and Hennelly (1980) have also shown that memory span and short-term recall are affected by speech rate.

Miles (1993) wrote that some dyslexics were unsuccessful on the polysyllables item of the Bangor Dyslexia Test if their speech rate was too fast. 'Unless they slow down their speech rate, they are at risk of saying the syllables of the word in the wrong order; this in its turn may lead to the 'false match for order' which is often found in dyslexics' spelling.' Similarly, in the present research, when reciting the five times table by giving just the products, several dyslexics showed a mismatch in order by omitting a product in the sequence, for example, participant D7 responded to the question '8 × 5' with '5, 10, 15, 25, 30, 35, 40, 45' while at the same time using his fingers to keep count. Košč (1974) recognised that a test of successively subtracting 7 from 100 could 'disclose disorders of counting silently', especially when subtracting over the tens. Thus here we are focusing on audible vocalisation, but it could have been that the dyslexic participants were less accurate than the controls, in part, because of errors in their silent counting, influenced by their internal speech rate being too fast due to the pressure of time, a potentially interesting theme for future research. Geary (1993) has stated that with a slow counting speed for addition, 'the representation of the augend (the first number) is more likely to decay (i.e., be forgotten) before the count is completed. In this case, even if the child generates the correct answer by using a computational strategy (i.e., counting), this answer might not become strongly associated with the problem'. Thus long-term memory representations of the basic mathematical facts are achieved through speed and accuracy in combination, which in turn are related to memory span.

(4) ***Category D:*** *Other audible vocalisation.* The behaviour of the dyslexics on this category was not significantly different to that found for the controls on multiplication. The reason for this may have been that initially the participants had been told to call out their answer (in the multiplication experiment) where they had not been able to use the delete key (this key was not available for use in the experiments). This accounted for a higher tally by the controls for this behaviour. However, on the other operations, the dyslexics performed significantly more Category D behaviour than the controls. This category included observation of sighing and 'Oh no' type responses akin to the findings of Miles (1993) on the Bangor Dyslexia Test. Thus this category

included the observation of exasperation, as well as comments that were very revealing and sometimes comical. We need to consider why it was that the dyslexics vocalised more than the controls. Perhaps the dyslexics were less able to inhibit their responses and therefore appeared more vocal.

It was as though their thinking was transparent at times. Such comments as:

(a) 'It's gone. I just had it' (D2 – multiplication) was an example of a participant trying to hold on to a thought – trying to remember it.

(b) 'I am slow at thinking' (D29 – multiplication) indicated that the participant was aware of slow processing of mathematical information.

(c) 'Come on!' (D14 – addition) showed the intent of the dyslexic participant to do as well as possible – with self-inflicted pressurisation.

(d) The participant said that his mind was full up and that he found it hard to move onto the next question (D19 – multiplication) – this indicated that the dyslexic brain became overloaded and could not continue to function until it had cleared.

Category A and C behaviours were related directly to the questions presented whereas those behaviours from Category B and D were extraneous to the specific task in hand. The dyslexics showed significantly more Category B and D behaviours on all operations (except multiplication in Category D) compared to the controls. This suggests that an important distinction needs to be drawn between helpful behaviours and those that appear to be unrelated to speedy and accurate performance. Thus the behaviour of the dyslexics appeared to adversely affect their speed and accuracy on the four operations and yet it was behaviour that was 'part and parcel' of their dyslexia.

17.9 Overall Conclusion

The interesting points that have arisen are:

(1) The acquisition of number facts is particularly challenging for dyslexics. It is suggested that paired-associate learning, verbal labelling and automatisation theories are relevant.

(2) The dyslexic 'age of gain', when most noticeable progress is made, is between 10 years 7 months and 12 years 7 months. This is 3–4 years later than non-dyslexics.

(3) There is evidence of *both* a maturational lag and a deficit/developmental disorder in dyslexia implicating the role of the cerebellum.

(4) The dyslexics had difficulty in memorising multiplication number facts that did not involve algorithms.

(5) On subtraction and more particularly on addition, the speed of the dyslexics is affected adversely, especially when crossing the ten barrier.

(6) Dyslexics are unable to respond as instantaneously as non-dyslexics on mathematical questions that involve the use of number facts.

(7) Dyslexics make use of 'anchor points' and transposition from one operation to another as strategies for working out the answer.

(8) Dyslexics may be influenced by a phenomenon known as the 'Matthew' effect from the Gospel according to Matthew (XXV: 29) where difficulties such as acquisition of number facts, memory for number facts, paired-associate learning, verbal labelling and articulatory and counting accuracy, exacerbated by stress and pressure, create an adverse effect on the dyslexic performance, which continues to accumulate over time. Point 9 reinforces this.

(9) Dyslexics display an unexpected age difference between 13 years 5 months and 15 years 4 months, where their knowledge of number facts appears to decline or plateaus, this being in contrast to the continuing progress of non-dyslexics at this age.

(10) Additional behaviours such as use of fingers, other bodily movement, audible vocalisation relating to the question and other audible vocalisation characterise the performance of dyslexics when they execute sums utilising the four operations. It generally appears that the dyslexics are 'doing as a substitute for naming' (T.R. Miles, in Miles and Miles, 1992, p. 97).

There are therefore a number of practical implications that arise as a result of this research. These are detailed in the next chapter.

CHAPTER 18

Practical Implications

18.1 Introduction

18.2 Acquiring Number Facts

18.3 The Age of Gain

18.4 Algorithms

18.5 Crossing the Ten Barrier

18.6 A Question of Speed and Accuracy

18.7 Anchor Points

18.8 Translating to a Different Operation

18.9 The 'Matthew' Effect

18.10 Unexpected Age Difference (UAD)

18.11 Additional Behaviour

18.12 Overall Conclusion

18.1 Introduction

In this chapter an attempt will be made to discuss some of the practical implications arising from the research.

18.2 Acquiring Number Facts

The notion of suitable training is of central importance. The participants in this research were at schools that particularly catered for dyslexics. Therefore it is likely that they had received a substantial amount of special training for their difficulties. However, in less favourable educational circumstances their speed and accuracy levels might well have been lower.

This research indicates that it would be wise to monitor and address dyslexic difficulties in number fact acquisition, on any of the four operations. The youngest dyslexics in this research had a mean age of 10 years 7 months and their performance was particularly weak in relation to both older dyslexics and the age-matched controls. It is possible that their difficulties were evident at a far earlier age and therefore an interesting project for the future would be to investigate number fact acquisition by younger dyslexics, with subsequent research on the most effective forms of identification and remediation. Literacy prognosis improves with early identification and support and there is reason to believe that the same could be true for mathematics. In addition we know that a proportion of dyslexics struggle with specific aspects of mathematics such as learning to tell the time and learning sequences in long algorithms (Ginsburg, 1997).

Considerable over-learning of number facts is recommended in order to enable a 'pairing' of the question to its answer (Done and Miles, 1978). In the researcher's own experience, dyslexics respond best when knowledge is linked or 'paired' to current interests, such as 'Harry Potter' (Rowling, 1997), especially when the ideas are generated by the students themselves. The learning of multiplication tables has been greatly enhanced by placing the multiplier and product on either side of each step in 'Harry Potter's staircase'. Such a topical approach has enlivened many a lesson and provided enjoyment, creativity and a lasting association to be formed for the number facts. Another student has made thematic posters of challenging multiplication tables, which have been displayed in her bedroom. The care with which the posters have been created, incorporating the student's own thoughts, has enabled her to build a relationship with the number facts in a unique way. One student has even placed number fact cards in the fridge – so that they act as a reminder on a regular basis.

The results have shown that dyslexics are not as readily able to cope with a fast rate of delivery. Miles and Wheeler (1977) showed that dyslexics have 'some kind of limitation in their ability to handle relatively complex stimulus material in a short time'. Therefore the teaching plan should include plenty of time for absorption of learning with less 'fast talk' by the teacher, but slower delivery that includes carefully chosen key words and phrases. Street (1976) wrote of the importance of specificity of words in instruction and explained in her own case that 'the more difficult she [the teacher] saw that I was finding the sum, the more words she produced', which served to confuse her further.

One dyslexic participant (D19 on multiplication) said that his mind was 'full up' and that he found it hard to move onto the next question. This example showed that dyslexics are prone to memory overload, especially when under the pressure of time. The researcher has noted that dyslexics can become completely unable to process information under these circumstances and therefore teachers need to give the dyslexic learner time to recover rather than becoming overwhelmed with more information. Similarly, perseveration of ideas from a previous example can cause confusion, exemplified by participant D27 (multiplication) being unable to answer the presented question because he was 'thinking of the last question – hence he was staring at the screen' (see Appendix G, section G.1).

Therefore dyslexics need time to acquire and work with number facts. This is reinforced by the age of gain shown next.

18.3 The Age of Gain

Dyslexics in the research made most noticeable progress between 10 years 7 months and 12 years 7 months, which was 3–4 years later than non-dyslexics. Miles et al. (2001) recognised a similar tendency and wrote: 'It seems likely that there are few or no skills, mathematical or other, that are downright impossible for dyslexics if they are given sufficient time and practice. At a given age, however, it is likely that they will not have "absorbed" as much as their nondyslexic peers'.

If the research conclusions are right it follows that practitioners should develop mathematical programmes for dyslexics which are designed to build the foundation skills in a multisensory way, at an appropriate pace for them. A long-term programme should include extra input on an understanding of the way in which our number system is organised and the patterns that are present, along with a range of helpful strategies and regular review of key number facts throughout. It is quite possible that pace of delivery of the present system leaves the dyslexic with unresolved gaps in their knowledge and that more time should be spent on getting the early skills clear.

Practitioners have in fact adopted such an approach (Chinn and Ashcroft, 1998) and found that a firm foundation of understanding, of reviewing mathematical skills expected of younger children, is vital before the introduction of more advanced concepts. This design is for secondary aged students but could also be adapted to suit the needs of the younger dyslexic in the Primary School setting.

Similarly, E. Miles (Miles and Miles, 1992, in the Overview) wrote of dyslexics displaying:

> frequent examples of confusion through the overloading of the memory and the perseveration of ideas from a previous example. It is not that a particular topic cannot be mastered; it is that dyslexics need more practice and experience than non-dyslexics if they are to succeed in doing so.

Thus the gift of time seems to be one of the most important considerations in designing a mathematics course suitable for the needs of dyslexics. The findings indicate that in the right circumstances some improvement in dyslexics' correctness and speed is at least possible.

The young dyslexics were more successful on mathematical questions that included algorithms. Bearing this finding in mind, it makes sense to exploit this particular preference of the dyslexics.

18.4 Algorithms

Turner Ellis et al. (1996) explain: 'The improved performance by all subjects as regards both correctness and speed when algorithms are readily available is clearly a matter of considerable importance for the practising teacher.' Dyslexics rely on one crucial algorithm; that numbers go up in ones (Pritchard et al., 1989). It was shown that dyslexics use their fingers or make marks on paper for some calculations (Miles, 1993, chapters 15 and 16), thereby using this algorithm to circumnavigate their memorisation difficulties.

Through personal observations in this research, it was found that several of the dyslexic participants displayed a sense of curiosity and a range of interesting observations about the mathematical tasks in the experiments. Many of the observations were concerning the design or were about patterns within the experiment. It seems worthwhile, therefore, for the dyslexic to discover further patterns within mathematics that he is unfamiliar with. This may require explicit teaching since one cannot assume that the dyslexic knows all aspects.

If the research conclusions are right, it follows that practitioners should encourage the learning of a whole range of algorithms in a wide variety of ways so as to minimise the number of facts to be remembered. Dyslexics need to increase their repertoire of algorithms thus making their approach to the task more efficient. Torgesen and Goldman (1977) proposed that the performance difficulties of learning disabled children could be explained in terms of 'their inability or lack of inclination to develop and use efficient task strategies'.

One efficient approach would be to teach facts that can be replicated, such as $42 + 8 = 50$ and $52 + 8 = 60$ where a knowledge of number bonds to ten $(2 + 8)$ proves an invaluable pattern to memorise. Practitioners do in fact encourage the use of patterns in order to help dyslexics generalise and classify their number facts and rules (see Chinn and Ashcroft, 1992, chapter 7 for further details). This logical approach emphasises the 'structure of mathematics and streamlines the learning of facts' thereby 'reducing the load on memory'. Number patterns are explored and sequences are discovered. Basic facts are prioritised into learning: addition facts from 0 to 9, number bonds to 10, concept development of place value, the pattern of adding to 9, adding doubles, multiplication and division facts using number spirals and block patterns, and the interrelationship of the four operations by developing an understanding of the link between concrete manipulatives and abstract symbols.

Chinn and Ashcroft (1998) advocate the use of learning the table facts by understanding. By presenting multiplication/division facts in a table square the basic structure of how the counted numbers are organised is illustrated. They state that: 'If information can be seen to be in patterns or if it can be organised in patterns, it is easier to learn.'

One particular pattern that caused some difficulty for the dyslexics was that of moving through the ten barrier when calculating.

18.5 Crossing the Ten Barrier

On subtraction and more particularly on addition, the speed of the dyslexics was affected adversely, when crossing the ten barrier. These results suggest that dyslexics could benefit from extra experience of counting across the ten barrier as fluently as possible. The aim of the extra practice would be to help counting become more automatic, thereby enabling resources to be re-allocated to other aspects of the mathematical process. Such counting skills are taken for granted in children's schooling and perhaps more attention should be given to the study and support of the dyslexic individual's counting rate and accuracy. This could be extended to include the crossing of the hundred, thousand, ten thousand, hundred thousand and million barriers both forwards and backwards, as well as moving into negative numbers over the zero barrier and overcoming the decimal barriers.

A 'barrier' is often traversed after the digit 9 when counting forwards and after a number with zero in the last place value position when counting backwards. The counting forwards from a 9 directly to the next number with a zero, for example in the units position, doesn't seem logical unless the system is explained and understood. Dyslexics are renowned for not picking up the obvious (Miles, 2002, personal communication). Money and measurement include the usage of the decimal point as a separator and therefore a working knowledge of the 'barrier' concept is important in many aspects of daily life. An interesting study for the future would be further research on the effect of these 'barriers' in the number system on dyslexic students.

These results call into question how familiar the dyslexic is with any mathematical situation that calls for some sort of re-labelling, such as minutes and hours, pence and pounds, where a barrier or separator is in operation.

Such barriers may be responsible for a lessening of speed and accuracy on a range of mathematical tasks.

18.6 A Question of Speed and Accuracy

Turner Ellis et al. (1996) state that, 'It is, of course, pointless to ask if a child is "good at multiplication" simpliciter, since he is likely to be more accurate and quicker with some products than with others.'

There is evidence that the performance of some dyslexic participants was affected by confusion as to which number in a multi-digit answer to type in first (see Appendix G, section G.1). Participant D1 (multiplication) liked to check the screen to see if his answer had been typed in correctly. Participant D2 (multiplication) said, 'I tend to get numbers the wrong way around', for example, $2 \times 8 = 61$, $6 \times 2 = 21$, $7 \times 2 = 41$, $2 \times 9 = 81$. For $1 \times 11 = 11$ the participant said, 'I could hardly get that one back to front!' He searched for the keyboard numbers and then checked up on the screen to see if the numbers had been typed in correctly, which the researcher noted was quite a demanding task.

Likewise performance could have been delayed because of confusion with the operation required, for example D2 (multiplication) was observed to say and do the following: 'Its gone . . . I just had it . . . I keep thinking its divide' (when the question was multiply). On question 5×5 he said, 'Is ten I think' and then used his fingers to arrive at the answer 25. On the latter example the multiplication sign had been confused with an addition sign.

These observations point to the need for practitioners to give dyslexics extra training in speaking and writing numbers down, raising the learner's awareness of potential errors that are likely to occur, as well as drawing attention to the identifying 'features' of each sign representing the four operations, to help build meaningful associations. Miles and Ellis (1981) emphasise that teaching methods that are most successful for dyslexics are those that are multisensory, structured and cumulative. 'Links need to be forged between inputs from the three different sensory modalities, vision, hearing and kinaesthesis... development of extra input routes facilitates lexical access.'

18.7 Anchor Points

Dyslexic participants were found to utilise 'anchor points' as a strategy for calculating 'surrounding' number facts, as shown by participant D12 (multiplication) who said, 'Nothing came (into my head) and then I remembered $9 \times 9 = 81$ and subtracted'. As a consequence it makes sense to plan to increase the number of anchor points that are available to the dyslexic, perhaps through the use of mnemonics for specific number facts. Multiplication and division number facts that were found to be most challenging for all participants were those from the 6, 7, 8, 9 and 12 tables especially with similar multipliers and quotients, such as 6×8, 8×8, $56 \div 7$ and $84 \div 12$. Therefore the most efficient anchor points to teach are those for some of the latter type of questions, such as the mnemonic: '6×8 went on a date and came back in as 48' or 'I ate eight things and was sick on the floor (rhymes with 64)' for 8×8. Such examples have been chosen to illustrate the importance of forming strong associations that are memorable.

One of the hardest division/multiplication facts was found to be 11×12, 12×11, $132 \div 11$ or $132 \div 12$. Within the teaching situation the present researcher has drawn particular attention to this finding and students have taken delight in knowing the 'hardest fact of all' that others find difficult. Again a successful association was presented to the dyslexic student.

Anchor points that involve the skill of doubling and halving numbers have been advocated by practitioners and dyslexic students as a way of working through to an answer (Deveaux, 1992).

There were many compensatory strategies used by the participants. One of these was to use a known number fact, for example in multiplication (e.g. $6 \times 3 = 18$), to work out an answer in another operation, such as division (e.g. the question $18 \div 3$ may be thought of as 'How many 3s make 18?'). Such a strategy had the advantage of increasing the participant's repertoire of number facts/anchor points. This approach is referred to as 'translating' from one operation to another and is discussed next.

18.8 Translating to a Different Operation

The dyslexic participants often translated from one operation to another, for example (see Appendix G, sections G.1 to G.4) from division to multiplication: participant D11 (division) counted up in 2s to find the answer for 14 ÷ 2; participant D12 (division) said, '11 times something . . .' in response to the question 88 ÷ 11. Subtraction was translated into a partial addition calculation; for example, participant D10 (subtraction) worked out 95 – 58 by '(tens) 5 add on up to 9 = 40, 5 from 8 = 3, 40 – 3', and addition was used for participant D14 (subtraction) when working out 51 – 28, by adding 28 + 2 = 30, then adding 20 and then 1. Thus dyslexics are adept at 'compensating', which according to Haylock (2001) is a term used to describe when one 'converts an addition or subtraction question into an easier question by temporarily adding or subtracting an appropriate small number . . . the trick in the strategy is always to be on the lookout for an easier calculation than the one that you have to do.'

It therefore makes sense to teach the commutative property of multiplication early in the training and with regular revision. This property is expressed algebraically as: $a \times b = b \times a$, thereby reducing the number of facts needed to be memorised. Similarly the dyslexic can be helped if he realises that addition can be done in any order, that subtraction is the inverse of addition, that multiplication can be thought of as repeated addition and that division can be likened to repeated subtraction. Thus by gaining an understanding of the interrelationship of the four operations, the number of facts to be memorised is reduced. The responses of the dyslexics in this research show that they were able to employ a wide range of strategies with which to achieve mental calculation. Such a skill is recognised as the basis of being numerate and indicates that dyslexics can possess an understanding of the way our numerical system operates – they just need to be guided as to the most efficient and time-saving ways to work out a problem.

When questioned it was found that the dyslexics used a variety of ways to calculate the HARD subtraction sums (see Appendix G, section G.4). It is worthwhile finding out how a dyslexic works out a problem in order to help them become more efficient if necessary. It follows that practitioners should ascertain the best style of learning to suit the student. Practitioners do in fact refer to two main types of mathematical personality caused, in part, by the way that mathematical information is processed. Sharma (1990) refers to quantitative (solving problems bit by bit, using logical progression, quantifying and approaching a task sequentially) and qualitative (intuitive, holistic, sees interrelationships between concepts, makes mistakes in the details of a procedure) mathematical learning personalities, with most learning personalities lying somewhere on a continuum between the two extremes. 'To acquire a high level of fluency in mathematics work, the elements of both learning styles must be integrated.' Similarly Chinn and Ashcroft (1998) refer to two cognitive styles: the inchworm and the grasshopper (rather like Sharma's quantitative and qualitative style respectively).

As Street (1976) concluded in her own case and that of another student: they had needed 'a teacher trained to understand the way our cognitive styles differed from those of other children, and who was also trained to adapt her teaching to our needs.'

18.9 The 'Matthew' Effect

The 'Matthew' effect discussed in section 17.7 (point 5) is undesirable. An awareness of the effect and how to avoid it would be beneficial.

It is advantageous initially to learn the number facts that are easier to acquire, in order to promote confidence and encouragement. This research proved that these number facts were the 1, 2, 3, 5 and 10 multiplication and division tables, especially with low multipliers and quotients. Often dyslexics learn through hearing a pattern such as in the 10 times table or the sequence of the 5 times table. The practitioner can be vigilant to any habitual errors that occur in these calculations, especially at the outset. It was noted that participant D7 (multiplication – see Appendix G, section G.1) made an error in his counting up of the 5 times table on his fingers, as follows: 5×5 was worked out on his fingers and came to 30, 8×5 was again calculated using fingers as '5, 10, <u>15</u>, <u>25</u>, 30, 35, 40, 45'. He therefore omitted 20. The researcher has noted in the course of teaching that an error committed in the first instance tends to reoccur consistently if not addressed.

A positive improvement can be fostered through skilled teaching. This should be provided with 'sufficient intensity, patience, sympathy and understanding. Perhaps, indeed, these qualities are more necessary to the teacher than any special pedagogic trick of technique or skill. The system of teaching which is adopted may matter less than the manner in which the instruction is imparted' (Critchley, 1970).

Just because a dyslexic student uses his fingers and has difficulty remembering number facts, this should not perpetuate the notion that he is not able to pursue the subject to a higher level. Indeed Jansons (1988) is one example of a dyslexic who has succeeded in mathematics despite his difficulties. He gained a place at King's College, Cambridge to read mathematics, obtained a distinction and then undertook a PhD in fluid mechanics. He then went on to become a lecturer in mathematics at University College London. Jansons may not have followed this path were it not for his teacher who had recognised his talents and given him encouragement.

Likewise Steeves (1983) recognised that dyslexics could be mathematically gifted but warned of possible dangers:

> If the needs of gifted children are not met by appropriate programming in school, the resultant frustration may cause them to become under-achievers or even high school dropouts. The highly intelligent dyslexic, already an under-achiever in the area of language, becomes doubly handicapped if his or her mathematical talent is not fostered or challenged.

This talent can exist alongside a 'lack of computational efficiency'.

Thus dyslexics need sympathetic and observant teaching to promote their abilities and raise their confidence in a subject that they may have potential for.

18.10 Unexpected Age Difference (UAD)

One of the most surprising and consequently important findings was that of the unexpected poorer performance of the old dyslexics in relation to the strong performance of the medium-age dyslexics and the old controls.

It is possible that the UAD phenomenon might cause dyslexic teenagers to be especially susceptible to adverse educational experiences leading to emotional difficulties akin to the 'Matthew' effect. In order to counteract this possibility, practitioners should be aware of the need to review number fact skills on a regular basis throughout the mathematical course. Review of even the $1\times$, $2\times$, $3\times$, $5\times$, $10\times$ and $11\times$ tables should be made. This helps to ensure that confidence is raised by the knowledge that the foundation skills are secure. Additionally this may help to reduce perseveration and slower decision-making (see points 3 and 4 in section 17.7).

The research results show that practitioners should be aware that associations once achieved by dyslexics when they are younger are not necessarily retained when older – especially if the knowledge has not been utilised recently. Therefore one needs to continually monitor progress: in the case of dyslexics there is extra danger that what they have learned may not be retained because they have had insufficient exposures.

By enabling the foundation skills to be more automatic through practice, the dyslexic learner will be able to concentrate more resources on other aspects of the mathematical programme, and have at his disposal as wider range of 'anchor points' or 'friends'.

Training in fast counting rate – especially when passing the ten (and other place value) barriers – could help the student progress. Likewise experience of writing numbers to dictation both fluently and accurately could promote progress.

Additionally, it might be profitable to consider giving the dyslexic extra training in verbal labelling of numbers at speed. If they can articulate numbers more readily, more resources become available for processing the problem.

18.11 Additional Behaviour

The dyslexic participants showed a preference for verbalising their way through a problem. This implies that they would benefit from the opportunity to learn the most efficient way to talk through a mathematical problem rather than work silently.

Kibel (1992) stressed the importance of linking language (a verbal description of the processes taking place) to action; showing that 'the language and manipulation seemed to work together in a mutually supportive way'.

For the teaching of literacy, the use of a Reading Pack is widely used. In mathematics the dyslexic learner benefits from a Mathematics Pack that is designed to review number facts and key memory pointers and to provide rehearsal of the main algorithms. The Mathematics Pack evolves throughout the teaching programme and the learner is encouraged to participate in the Pack's construction and to review it regularly.

Practical manipulation, exploration and design by the dyslexic learner seem to be a natural progression when learning, from the number of bodily movements and verbalisations made by the dyslexic participants in the research. It seems reasonable to suppose that dyslexics would benefit from activities that involve 'doing' such as being required to: count on number lines which fosters an understanding of place value and positioning and pattern in mathematics; use weaving cards to help the student practise their division and multiplication facts; learn the 'gypsy' method of multiplication on the fingers; apply knowledge of an algorithm for the 9 times table (the sum of the first and second digits in the product always adds up to 9), including another finger technique, this time for working out the 9 times table.

Griffiths (1980) writes of the possible advantage to the dyslexic child of chanting his tables and thereby encouraging an automatic response – proposing this idea as scope for future research. Hubicki (2001) has developed a 'Colour-Staff' to help people to read music. The 'Colour-Staff' has the 'capacity to highlight, through colour, music's beautiful symmetry of patterning'. Likewise some sort of colouring system could be devised to show the patterning within number facts.

T.R. Miles (in Miles and Miles, 1992) advocates the use of structured material stating:

> Dyslexics are better at 'doing' than at 'naming', and a foundation of 'doing' is essential. The great advantage of structured materials is that they ensure that 'doing' comes first and 'naming' afterwards . . . Once the necessary foundations have been acquired by 'doing', however, then the abstract reasoning, the generalizations, and the discoveries – which, after all, constitute the really exciting parts of mathematics – need present him with no problem. (p. 97)

The participants responded favourably to the use of a computer in the research. The computer engaged their attention and was able to record their responses accurately. The advantage of using of computer software to develop calculation and number fact skills are that it can provide:

- a sense of 'doing';
- motivation and enlivening of the task;
- skills specific to the needs of the dyslexic learner;
- continuous and immediate feedback with rewards;
- the opportunity to programme timed presentation and responses;
- personal confidence whereby a student is not judged against another;
- reduction of stress in the learning situation;
- the chance for the student to learn at his or her own optimum pace and level;
- self-choice;
- prestige;
- another medium for presenting and working with mathematics;
- regular rehearsal of skills;
- intense training.

There was additional behaviour that did not appear to contribute helpfully to the task in hand, such as some bodily movements and verbalisation (see chapter 15, Category B and D behaviours). We need to consider if this behaviour could be profitably reduced. Certainly, teachers should expect to see this behaviour and that attempts to inhibit it might give dyslexics yet another thing to do. Alternatively, perhaps the 'behaviour' is an important ingredient for learning. This is a matter for future research.

18.12 Overall Conclusion

This research has raised a number of practical implications for teachers of dyslexics:

(1) Dyslexic children are very likely to need specific support in mathematics.

(2) The obvious is likely to be overlooked by the dyslexic, including patterns, the sign of the operation and terminology. We should not assume that something is known or remembered, whatever the age of the student.

(3) Dyslexics would benefit from acquiring number fact skills and knowledge from as early an age as possible. Over-learning of number facts is recommended.

(4) The dyslexic makes particular gains in speed and accuracy for number facts between the age of 10 years 7 months and 12 years 7 months. This is approximately 3–4 years after non-dyslexics. Parents and teachers can be forewarned of this possibility thereby having more realistic expectations for the dyslexic both in coursework and assessment. This could have the effect of less negativity and a more positive approach towards the dyslexic's performance.

(5) Dyslexics aged from 13 to 15 years are likely to show an unexpected age difference (UAD) where their performance with mathematical number facts and mental calculation needs boosting – this can be achieved with regular review. The assumption that number facts are 'secure' at this age may be incorrect. The best policy for a dyslexic is to have his number skills monitored and reinforced throughout his mathematical schooling.

(6) It is likely that dyslexics will take longer to answer mathematical questions involving the four operations and therefore they will need more time to

complete their work. Extra time may also be appropriate on tests of mental calculation and formal assessment of mathematics.

(7) In order to counteract the 'Matthew' effect dyslexic students need help in realising that just because they find memorisation of the basic number facts difficult this does not preclude them from succeeding in mathematics with suitable training and appropriate strategies. It follows that teachers should be careful to promote self-esteem in dyslexics – for this may be lost if they are slow at mathematical tasks and continually get them wrong.

(8) Suitable training for the dyslexic might include:

(a) development of a wide range of secure anchor points;
(b) experience in translation skills whereby dyslexics can translate a sum from one operation to another;
(c) use of efficient strategies such as mnemonics for circumnavigating memory difficulties with number facts;
(d) enhancement of knowledge of patterns within the number system;
(e) some sort of help to prevent or reduce 'mental blocks' that can sometimes occur in the dyslexic when a mathematical task is overwhelming;
(f) the dyslexic may need training in some form of articulatory fluency in reading numbers, counting – especially across 'barriers' such as the ten barrier – and in the writing of dictated numbers.

(9) The research raises awareness of the difficulties experienced by dyslexics on:

(a) algorithms that do not have obvious patterns;
(b) questions that involve the crossing of a place value 'barrier' such as the ten, hundred, thousand, ten thousand, hundred thousand and million 'barriers', to name but a few.

This awareness encourages appropriate teaching support.

(10) In view of the number of errors made by the dyslexics, it is therefore important to ensure that they have sufficient understanding of the number system. This will enable them to judge whether an answer is reasonable or not. Dyslexics are prone to typing in wrong instructions into calculators and accurate estimating skills would be of benefit.

(11) Parents of dyslexic children can do much to provide mathematical support for their child. With greater awareness of the type of difficulties that their child might have, they can be guided to use appropriate strategies to rehearse number facts, perhaps more regularly than is possible at school.

(12) The practitioner should not be 'put off' by 'additional behaviour' exhibited by the learner. It may be necessary to work alongside this behaviour with a positive attitude.

(13) Older dyslexics may find that their mathematical difficulties are exposed at various points in their adult life. This may be in their chosen work or in social settings.

(14) If a mathematical task involving any of the four operations is hard for a non-dyslexic, it is likely to be especially hard for a dyslexic.

The final chapter entitled 'Summary and Conclusions' follows.

Part V Summary and Conclusions

<u>CHAPTER 19</u>

Summary and Conclusions

19.1 The Present Research
19.2 The Four Operations
19.3 Correctness
19.4 Speed
19.5 Additional Behaviour
19.6 Comparing the Four Operations
19.7 Research Questions
19.8 Main Issues for Discussion and Practical Implications
19.9 Relevant Theories of Dyslexia and Related Themes
19.10 Future Research
19.11 Justification

19.1 The Present Research

The aim of the present research was to investigate the correctness and speed of dyslexic boys on specific questions involving the four mathematical operations of multiplication, division, addition and subtraction. The performance of the dyslexics was compared with that of non-dyslexic boys matched on chronological age and reasoning skill. The participants were divided equally into three age bands:

(1) a young age band ranging from 9 years 5 months to 11 years 4 months;
(2) a medium age band ranging from 11 years 5 months to 13 years 4 months;
(3) an old age band ranging from 13 years 5 months to 15 years 4 months.

In addition, a comparison was made on some tasks (multiplication and simple reaction time) with non-dyslexics matched with the dyslexics on spelling age.

19.1.1 Experimental Precautions

Experimental precautions were taken that included a Simple Reaction Time Test and a Reading/Key Search Reaction Time Test. These tests were designed to ascertain any disadvantage that the dyslexics might have in reading and performing the mathematical questions. In the light of these results no adjustments to the main experimental findings were required.

19.2 The Four Operations

There were four main experiments, each based on one of the four operations. The mathematical questions were presented one at a time on a computer screen, and the participants were timed on how fast they could respond to each question by typing in their answer on a number keypad. The computer logged participant responses.

The questions for each of the four operations were:

(1) Multiplication –144 questions including all combinations ranging from 1×1 to 12×12.

(2) Division – 144 questions including all combinations ranging from $1 \div 1$ to$144 \div 12$.

(3) Addition – 75 questions divided equally into five categories: low addends not crossing the ten barrier, low addends crossing the ten barrier, high addends not crossing the ten barrier, high addends crossing the ten barrier and 'hard' questions that involved a double-digit addition onto a double-digit with 'carrying'.

(4) Subtraction – 75 questions divided equally into five categories like addition: low subtrahends not crossing the ten barrier, low subtrahends crossing the ten barrier, high subtrahends not crossing the ten barrier, high subtrahends crossing the ten barrier and 'hard' questions involving subtraction of a two-digit number from another two-digit number with 'borrowing'.

19.3 Correctness

Four chapters on Correctness (Chapters 6–9) provide the results on each of the four operations in turn. The design of each chapter is similar for ease of comparison. The chapters contain:

(1) the aims of each chapter – detailing the research questions being answered in the chapter;

(2) overall comparisons – the mean proportion of correct responses for each age band and group;

(3) tasks within each operation – for multiplication and division these are the twelve tables from 1 to 12. For addition and subtraction these are the five categories of questions concerning low and high addends/subtrahends and sums involving crossing and not crossing the ten barrier. The fifth category includes 'harder' sums with two pairs of 2-digit numbers including high addends/subtrahends in the units position with the resulting sums crossing the ten barrier with 'carrying' or 'borrowing'. The results for each group age band are presented in turn;

(4) comparing age bands within the separate groups – the performance of the three age bands within each group. A comparison is made between the young and medium age bands and the medium and old age bands in each group;

(5) order of difficulty – the order of difficulty for the groups and age bands on multiplication/division tables and addition/subtraction categories;

(6) special numbers combinations that are more likely than others to generate errors;

(7) chapter summary with the research questions answered.

19.4 Speed

Four chapters on Speed (Chapters 10–13) provide the results on each of the four operations in turn. The design of each chapter is similar for ease of comparison. The chapters contain:

(1) the aims of each chapter – detailing the research questions being answered in the chapter;

(2) overall comparisons – the mean and median response times by group and age;

(3) tasks within each operation – as for (3) on 'Correctness';

(4) differences between dyslexics and non-dyslexics on tasks within each operation. Comparisons are made for each age band;

(5) comparing age bands within the separate groups – as for (4) on 'Correctness'.

(6) order of difficulty – as for (5) on 'Correctness';

(7) topographical terrain(s) – presenting the mean response times for each group age band on the tasks within the four operations;

(8) special number combinations that are more likely than others to generate errors;

(9) chapter summary with the research questions answered.

One other chapter called 'Instantaneous Responding' was devoted to whether the participants could respond 'in one'. An instantaneous response is one that the participant gives without having to work out the answer. A response time band of 0–1.99 seconds was chosen as an operational definition of an 'instantaneous' answer. Earlier work by Pritchard et al. (1989) had raised the issue of whether people could respond 'in one' to multiplication questions and this provided the starting point for the present research. The present results showed that the dyslexics were less able, in all age bands, than non-dyslexics to respond 'instantaneously'.

19.5 Additional Behaviour

Two further chapters complete the results of the Main Experiments. Chapter 15 is unusual in that it concerns 'Additional Behaviour'; such observations are not often included in research reports on dyslexia, but would merit attention in that valuable data are gained. The observations were inspired by the work of Miles (1993) when describing the pattern of difficulties found in dyslexia. A literature search revealed the observations by MacMeeken (1939) of additional behaviour with emphasis on the importance of noting '*how*' tasks are performed.

In this research, the performance of the dyslexics was characterised by such additional behaviours as: use of fingers, other bodily movement, for example running fingers through hair, audible vocalisation relating to the question and other audible vocalisation including sounds made or words said in such a way that the task appeared as a challenge. Of the four categories of additional behaviour, the dyslexics displayed 'other bodily movement' and 'other audible vocalisation' the most often. The behaviours noted were also more prevalent in the youngest dyslexic age band and declined with age. For the dyslexics most of these behaviours were observed with multiplication, then addition, division and lastly subtraction.

19.6 Comparing the Four Operations

The results on the four operations were compared in respect of correctness and speed in Chapter 16. The dyslexics were most correct on addition and then on multiplication, subtraction and lastly division. Overall the dyslexics responded most quickly on multiplication then division, addition and lastly subtraction. Thus subtraction was the hardest of the four operations for the dyslexics as judged by correctness and speed. When Spearman's rho was applied it was found that overall, the order of difficulty of the tasks (tables or categories in each operation) for the groups and age bands were significantly the same for both correctness and speed. These results are reported in the sections entitled 'Order of Difficulty' in chapters 6 to 13. Therefore if non-dyslexics found particular tables or categories 'hard' then dyslexics would correspondingly find these same tables or categories also to be a 'challenge' in terms of accuracy and speed. Such agreement enabled a comparison between multiplication and division to be made of the overall order of difficulty of the tables from 1 to 12. This comparison showed that table order for both operations was marginally correlated for correctness and significantly correlated for speed. The 8× and 12× table, both for multiplication and division, were the least accurately and more slowly answered of all the tables. Those categories that crossed the ten barrier in both addition and subtraction were also the least correctly and more slowly answered of the categories. Details were also reported on the number of instantaneous responses made by the two groups for each operation.

19.7 Research Questions

Eight research questions were presented in Chapter 2, and these are shown here with their corresponding answers.

When performing mathematical operations of multiplication, division, addition and subtraction:

1. *Do dyslexics make fewer correct responses than suitably matched non-dyslexics?*

The answer to this question is 'yes'. When dyslexics were matched with non-dyslexics of their own age, they made fewer correct responses on questions involving the four operations. This was particularly the case for dyslexics aged from 9 years 5 months to 11 years 4 months.

2. *Do younger dyslexics make fewer correct responses than older dyslexics?*

The answer is 'yes' and 'no'. The young dyslexics were at a distinct disadvantage as judged by the number of correct responses when compared to the older dyslexics. This was found on all operations. On some tasks in each operation the dyslexics in the middle age band performed more accurately than the dyslexics in the old age band. This was termed an 'unexpected age difference' (UAD) that was not shown by the non-dyslexics.

3. *Are there any special number combinations that are more likely than others to generate errors?*

The answer is 'yes'. The number combinations that generated more errors for the dyslexics were found on multiplication and division tables with no obvious algorithms. On a selection of such questions (e.g. 6×7) the performance of the youngest dyslexic group was as accurate as that of the non-dyslexics who were approximately three years younger than them. For division the young dyslexics performed differentially better on questions with algorithms than without in comparison to their similar age matched controls. Thus the dyslexics relied more on the presence of algorithms for accuracy. Overall the dyslexics were more accurate when adding low rather than high addends and also not crossing rather than crossing the ten barrier on addition and subtraction questions.

4. *Do dyslexics need more time than non-dyslexics?*

Again the answer is 'yes'. Dyslexics took longer than the non-dyslexics on all operations.

5. *Are younger dyslexics slower than older dyslexics?*

The answer to this question is 'yes' and 'no'. The answer is similar to that for question 2. The young dyslexics were distinctly slower than the older dyslexics on all four operations. An 'unexpected age difference' (UAD) between the two older dyslexic groups was also found for speed as had been shown on accuracy. This was evident on some tasks in addition and division where the dyslexics in the middle age band performed as well as or faster than the dyslexics in the oldest age band. The controls did not show any instance of a UAD on any operation.

6. *Are there any special number combinations that are more likely than others to take more time?*

The answer is 'yes'. Again, on tables with no obvious algorithms the dyslexics took longer than non-dyslexics; for example, on multiplication the young dyslexics took longer to answer than non-dyslexics who were approximately three years younger. Thus on products specifically chosen because they require memorisation, the young dyslexics performed as correctly as the SA controls but as regards speed the young dyslexics were slower than the young SA controls. Crossing the ten barrier had a bigger effect on the dyslexics than the non-dyslexics on addition.

7. *Are non-dyslexics more likely than dyslexics to be able to respond instantaneously?* (This is a special case of speed.)

The answer is 'yes'. A time of 0–1.99 seconds was chosen to represent an 'instantaneous' response. Within this framework, the dyslexics were less able, in all age bands, than non-dyslexics to respond 'instantaneously'.

8. *Is the behaviour of dyslexics when responding different from that of non-dyslexics?*

One of the most interesting findings was that of the additional behaviour of the dyslexics while responding to the questions. This behaviour was divided into four categories: use of fingers for working out, other bodily movement, for example running fingers through hair, audible vocalisation relating to the question and other audible vocalisation such as comments of exasperation. The additional behaviour decreased with age for the dyslexics but this trend was not evident for the non-dyslexics. Therefore the behaviour of dyslexics is different from non-dyslexics and the additional behaviours given characterise the performance of the dyslexics.

19.8 Main Issues for Discussion and Practical Implications

There were a numbers of issues raised in the discussion of results and possible theoretical reasons were proposed (Chapter 17). Practical implications (Chapter 18) of the findings also followed the same themes as those discussed in the previous chapter. The main issues were:

(1) *Acquisition* – a discussion of the particularly weak performance of the young dyslexics in relation to both the older dyslexics and the non-dyslexics. Their

different performance was linked to a number of well-known theories of dyslexia: paired-associate learning (for example: Done and Miles, 1978), verbal labelling difficulties (for example: Miles and Ellis, 1981; Ellis and Miles, 1981) and automaticity (the extensive work of Nicolson and Fawcett – see reference section). The notion of suitable training was emphasised, with early identification of difficulties and the need for considerable over-learning. Dyslexics need time to acquire and work with number facts.

(2) *The Age of Gain* – the age at which most improvement was shown in accuracy and speed. For both accuracy and speed in multiplication the dyslexics made most progress between the age of 10 years 7 months and 12 years 7 months. For the controls matched on spelling age the greatest gain was found to be between 7 years 8 months and 8 years 9 months. Thus the 'age of gain' of the dyslexics was 3–4 years later than the non-dyslexics. Links were made to the research of Fleischner et al. (1982), Ashcraft and Fierman (1982), Miles et al. (2001) and the writings of Chinn and Ashcroft (1998) and E. Miles (1992). Practically the gift of time was stressed as one of the most important considerations in designing a mathematics course suitable for the needs of dyslexics.

(3) *Deficit or Delay* – while the results appeared to support the theory of a maturational lag or delay in dyslexia, reports from other research were presented to show that deficits as well as delays had been found in dyslexia. The work of Nicolson and Fawcett (1994a) showed evidence of a 'delay' on a selective choice reaction task, for example, and yet Nicolson et al. (1999) found error rates in dyslexic adults even on tasks that had been over-learned, suggesting a deficit. Other examples are given both in the discussion and the literature review in Chapter 1. The Connectionist Model proposed by Brown and Loosemore (1994) received a special mention with the reference to the possibility that 'dyslexics suffer from a fairly general lack of cognitive resources' (Turner Ellis et al., 1996).

(4) *Performance Anomalies* – particular aspects of the mathematical tasks that the dyslexics showed difficulties with in the research, such as not making the same improvement on accuracy with age as the controls. Other performance anomalies included: difficulty with multiplication and division tables that had no obvious algorithm; performing more slowly than age-matched controls on

addition when the task involved crossing the ten barrier; not being able to respond as often as age-matched controls within 0–1.99 seconds on what was classified as 'instantaneous responding'.

(5) *The Four Operations: some thoughts* – specific findings on the four operations with possible reasons for them. One example was that subtraction was the slowest operation for both groups possibly because it is harder to count backwards than to count forwards. The concept of 'anchor points' was raised – an anchor point is a known number fact, from which other number facts are derived. An example of this is given in the actual words spoken by a dyslexic participant (D12, multiplication – see Appendix G, section G.1) 'Nothing came [into my head] and then I remembered $9 \times 9 = 81$ and subtracted' to find the answer.

(6) *Unexpected Age Difference (UAD)* – between the two older dyslexic age bands. The controls showed an improvement in accuracy and speed with age but this trend was not so pronounced with the dyslexics. Indeed several occasions were found where the medium-age dyslexics performed as well as and also better than the old dyslexics, a phenomenon not displayed by the non-dyslexic group, hence the adoption of the term Unexpected Age Difference. The difference between the old dyslexics and old controls was greater than that generally found between the two experimental groups in the medium-age band. As a consequence it is possible that the UAD phenomenon might cause dyslexic teenagers to be especially susceptible to adverse educational experiences. The 'Matthew' effect described by Stanovich (1986) is particularly relevant. The words 'For unto everyone that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath' (Gospel according to Matthew, XXV: 29) take on a particular meaning when applied to the difficulties experienced by dyslexics when performing mathematical tasks that involve the four operations. This is exemplified in the detrimental cumulative effect in: difficulty of acquisition, later age of gain, lack of practice of number facts as well as memory difficulties exacerbated by stress and pressure particularly felt between 12 and 14 years of age, leading to an Unexpected Age Difference. It therefore makes sense for practitioners involved with dyslexics to be sensitive to any possible 'Matthew' effect.

(7) *Additional Behaviour* – four categories of behaviour shown to characterise the behaviour of the dyslexics: use of fingers, other bodily movement, audible vocalisation relating to the question and other audible vocalisation. It is suggested that dyslexics would benefit from the opportunity to learn the most efficient way to talk through a mathematical problem rather than work silently. T.R. Miles (in Miles and Miles, 1992) advocated a mathematical programme that involved 'doing' thereby promoting a practical approach to the subject.

19.9 Relevant Theories of Dyslexia and Related Themes

The discussion of the findings prompted a literature search of relevant theories of dyslexia and related themes, the most important of which were:

- research on dyslexia and mathematics;
- relevant mathematical research and knowledge not necessarily connected to dyslexia directly;
- issues of memory;
- articulation and phonology;
- evidence of delay and deficits in dyslexia;
- paired-associate learning and verbal encoding;
- responding at speed – automaticity;
- the cerebellum deficit;
- the magnocellular deficit;
- inhibition;
- additional behaviour – fingers, bodily movements, verbalisation;
- Gerstmann syndrome;
- other emotional and motivational factors such as anxiety, stress and personal approach towards tasks.

The essential outcome was that the responses given by dyslexics when performing mathematical tasks are 'part and parcel' of the pattern of difficulties that characterise dyslexia in much the same way as 'the difficulties experienced by dyslexics in mathematics are manifestations of the same limitation which also affects their reading and spelling' (T.R Miles, in Miles and Miles, 1992, p. xi).

19.10 Future Research

A central finding of the research is that if a mathematical task involving any of the four operations is hard for a non-dyslexic, it is likely to be *especially* hard for a dyslexic. It would be of interest to identify aspects of mathematics that pose the most difficulty for non-dyslexics and this knowledge could act as a guide to predicting similar areas of difficulty for dyslexics. Likewise research could be conducted in the area of special needs in a broader sense to determine if there is a similar pattern of results.

Additionally future research could identify areas in mathematics that are a specific challenge to dyslexics or students with ADHD or other special needs that aren't a challenge for non-dyslexics. One example is that of time estimation and general issues relating to time, for example pacing oneself in examinations so as to be able to complete or awareness of the length of tasks. Research could centre on a number of aspects including *inter alia*: awareness of time generally over long time spans (an awareness of historical events through the passage of time, and life span events for the individual). This could include studying accuracy in telling the time and a review of what difficulties might be in this respect and why, with an outcome that addresses improved teaching and use of resources.

Within the field of dyslexia, different strengths and weaknesses could lead to variations in mathematical performance, for example, some dyslexics like to work mathematical problems out systematically while others prefer to calculate internally with little evidence of their working on paper. Therefore to examine these differences against performance could help in developing more appropriate and effective remedial or coping strategies. This could lead to helping non-dyslexics whose acquisition of mathematics is weak.

Positive research could be conducted on identifying the areas of mathematics in which dyslexics do particularly well including interviewing successful dyslexic mathematicians and learning from their experience. The skill of asking the right questions would be paramount. It may be important to take time in the research setting to listen to the comments made by dyslexics about their performance in mathematics, helping researchers to gain insights that may not have been considered before.

This research has found that there is a difference between dyslexics and non-dyslexics in age of acquisition and gain in performance. Research could be usefully employed on how this knowledge could be practically incorporated into design of the mathematical curriculum, teaching plans, computer software, assessment tools and examination preparation and marking. Further to this a clearer understanding of how the language of mathematics is acquired and remembered might help in honing the skills of the dyslexics. With reference to the adult population, what current life skills in mathematics are used in daily life and how successful has the acquisition been for dyslexics and non-dyslexics?

Investigation into the nature and appropriateness of mathematical resources, for parents and helpers, could be carried out to promote support for dyslexic students who need regular out-of-school practice. The results of this kind of research can be used in developing effective products.

An interesting project for the future would be to focus on speed of response or automaticity in mathematics as a way of identifying a dyslexic. Would it be possible to identify dyslexia through the mathematical medium? This could help in separating a diagnosis of dyslexia against other special needs such as ADHD.

The research findings highlighted the challenge of crossing the ten barrier. Within mathematics there are similar 'barriers' to conquer, for example, measurement and the different units (mm, cm, m, km), money (pounds and pence) and time (seconds, minutes, hours). It would be interesting to investigate how dyslexic performance differs from that of non-dyslexics in tasks associated with manipulating these concepts assessed under timing and accuracy criteria. This feature within mathematics touches on the lives of adults as well as children and research could therefore be extended to examine this.

A question arises regarding the 'additional behaviour' given in the findings, for are these noted behaviours related to lack of inhibition or other factors? Do the additional behaviours observed in this research affect the performance of a dyslexic student? In what way is this performance affected? What changes in practice would help in improving performance? Future research would benefit from more systematic observations of 'how' tasks are done by differing groups of special needs. One consideration in this particular area might be in the measurement of articulation in counting, especially across the ten barrier in view of developing training strategies. This type of research might help in diagnosis of any learning difficulty.

The dyslexics in this research made use of their fingers to calculate problems more *often than the non-dyslexics. It would be interesting to investigate the effectiveness of their finger usage in the light of the similarity of dyslexics' symptoms with those of* the Gerstmann syndrome, one symptom of which is finger agnosia. This line of enquiry deserves further systematic research.

All these aspects could be studied using age benchmarks to determine differences. It is hoped that early detection and therefore early remediation would promote confidence and success with the subject. It appears that different ages experience different difficulties, which lead on to the adult population who may not have gained from research findings as yet. Their remediation may take a different form and should be sympathetic to the needs of the adult learner.

'My mind is full up' was a comment made by one of the dyslexic participants. This kind of statement could suggest that stress might contribute towards a type of 'mental block' perhaps brought on by time constraints. Could there be a physical explanation for this situation examined through brain activation research? What measures could be taken to train dyslexics to overcome this occurrence, or what changes to testing practice could be usefully adopted to enable the dyslexics to perform at their best?

The field of dyslexia and mathematics research is in its infancy in comparison to the discoveries in literacy but it seems that there is far more to dyslexia than literacy difficulties and it is anticipated that this research will help to increase understanding of the bigger picture.

There are primarily two possible limitations in the research that could have produced a different pattern of results. Firstly ADHD was not specifically tested for in the selection of participants. Secondly, a control group matched with the dyslexics on reading rather than spelling could have been incorporated into the design, as is the more common practice.

The researcher would, if refining this research, pursue a longitudinal study over a ten year period from age 6 to 16, employing an epidemiological paradigm selecting an experimental dyslexic and matching controls when diagnosis has been concluded at say age 10. Performance of participants on all four operations would be assessed on an annual basis, with supplementary quantitative data being obtained from teachers on each participant.

19.11 Justification

The researcher believes that despite these improvements, the thesis presented makes a significant and original contribution to knowledge because: (1) no comparable systematic analysis of dyslexic difficulties on the four mathematical operations has been undertaken in the published literature; (2) the volume of data collected has enabled age comparisons to be made even at the level of sub-operations; (3) an expanded analysis of some of the cognitive processes involved in the operations has enabled evidence to be adduced that can be contextualised in research literature on dyslexics; (4) whilst contributing radically new insights that require certain aspects of current orthodoxies to be challenged. These insights have application in the acquisition of mathematical skills by dyslexics and implications for how they can best be taught.

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Appendices

APPENDIX A

Participant Details for Stage 1 and Stage 2

Stage 1: Participant Details for the Multiplication Experiment

Key:

D = dyslexic

C = chronological age control

S = spelling age control

CA = chronological age (in months)

SS = spelling score (raw score)

MS = matrices score (raw score)

BDT = Bangor Dyslexia Test (number of pluses out of a maximum of 10)

BDT* = Bangor Dyslexia Test (number of pluses out of a maximum of 8 – the Subtraction and Tables sub-items having been omitted)

Table A.1 Young dyslexics

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
D1	132	21	40	8.0	6.5
D2	129	22	45	8.5	6.5
D3	126	22	39	8.5	7.0
D4	129	23	41	9.0	7.5
D5	126	28	43	7.5	6.0
D6	128	30	45	7.5	5.5
D7	129	30	40	8.5	6.5
D8	120	32	40	4.5	3.5
D9	131	34	49	6.0	4.5
D10	123	34	41	5.0	4.0
Group mean	127.3	27.6	42.3	7.3	5.75
Standard deviation	3.65	5.17	3.16	1.58	1.34

Table A.2 Medium-age dyslexics

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
D11	151	35	48	8.5	7.0
D12	141	40	50	4.5	4.0
D13	143	40	51	6.0	5.0
D14	158	45	44	5.5	4.5
D15	159	50	46	7.5	6.0
D16	138	50	45	6.0	5.0
D17	144	53	52	4.5	3.5
D18	160	56	40	4.5	4.0
D19	158	58	51	6.5	5.5
D20	160	61	43	4.5	4.0
Group mean	151.2	48.8	47	5.8	4.85
Standard deviation	8.85	8.60	4.03	1.40	1.08

Table A.3 Old dyslexics

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
D21	173	40	53	6.5	5.0
D22	161	56	53	6.0	4.5
D23	161	58	46	4.5	3.5
D24	168	64	47	4.5	4.0
D25	177	66	51	5.0	4.5
D26	169	68	56	8.5	6.5
D27	177	69	46	5.0	4.0
D28	174	70	48	5.0	4.0
D29	175	70	47	8.0	7.0
D30	178	72	49	5.0	4.0
Group mean	171.3	63.3	49.6	5.8	4.7
Standard deviation	6.34	9.73	3.47	1.44	1.16

Table A.4 Young CA controls

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
C1	125	65	40	2.0	1.0
C2	125	63	42	2.5	1.0
C3	115	71	33	1.5	1.5
C4	125	66	42	1.5	0.5
C5	118	51	38	2.5	2.0
C6	120	58	41	3.5	2.0
C7	113	60	36	3.0	2.0
C8	120	58	42	1.5	1.5
C9	117	52	41	3.0	2.5
C10	119	47	28	3.5	2.0
Group mean	119.7	59.1	38.3	2.45	1.6
Standard deviation	4.24	7.49	4.69	0.80	0.61

Table A.5 Medium-age CA controls

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
C11	137	76	44	3.0	2.0
C12	147	72	46	3.0	2.5
C13	145	76	43	2.0	1.5
C14	139	80	43	2.5	1.5
C15	139	79	45	3.0	2.0
C16	137	93	41	3.0	2.0
C17	138	80	42	2.5	2.0
C18	149	81	48	3.0	2.0
C19	155	79	49	2.5	2.5
C20	160	76	45	3.0	2.5
Group mean	144.6	79.2	44.6	2.75	2.05
Standard deviation	8.11	5.55	2.55	0.35	0.37

Table A.6 Old CA controls

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
C21	161	88	48	3.0	2.5
C22	173	92	47	1.5	1.5
C23	161	81	57	0.5	0.5
C24	171	84	46	2.5	1.5
C25	163	95	48	1.0	1.0
C26	174	90	51	1.5	0.5
C27	171	87	44	2.5	1.5
C28	175	90	54	1.0	0.5
C29	174	91	46	2.5	2.5
C30	170	93	52	2.5	2.0
Group mean	169.3	89.1	49.3	1.85	1.4
Standard deviation	5.52	4.23	4.08	0.85	0.77

Table A.7 Young SA controls

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
S1	89	21	34	3.0	2.5
S2	87	22	37	3.5	2.0
S3	88	24	25	3.0	1.0
S4	94	24	25	3.0	2.5
S5	86	28	22	3.0	1.5
S6	96	30	24	1.0	0
S7	87	30	20	1.5	0
S8	90	30	20	3.0	2.0
S9	102	34	28	3.5	2.0
S10	99	35	24	3.0	2.5
Group mean	91.8	27.8	25.9	2.75	1.6
Standard deviation	5.61	4.87	5.65	0.82	0.97

Table A.8 Medium-age SA controls

Participant number	*C A*	*SS*	*MS*	*BDT*	*BDT**
S11	92	37	45	0	0
S12	99	40	37	2.5	0.5
S13	113	40	52	2.0	1.5
S14	111	44	29	1.5	1.0
S15	116	49	39	3.5	2.5
S16	101	50	42	1.0	0.5
S17	114	52	37	0.5	0.5
S18	107	55	32	2.5	1.5
S19	102	55	26	1.0	1.0
S20	97	60	43	2.5	2.0
Group mean	105.2	48.2	38.2	1.7	1.1
Standard deviation	8.16	7.66	7.81	1.09	0.77

Table A.9 Old SA controls

Participant number	*CA*	*SS*	*MS*	*BDT*	*BDT**
S21	106	39	28	0.5	0
S22	106	55	43	2.5	1.5
S23	105	57	51	3.0	2.0
S24	109	65	42	1.0	0.5
S25	119	66	46	0	0
S26	121	68	43	1.0	0
S27	118	69	39	2.5	2.0
S28	121	71	37	2.5	2.0
S29	99	71	48	2.0	1.0
S30	121	71	47	2.5	2.0
Group mean	112.5	63.2	42.4	1.75	1.1
Standard deviation	8.33	10.23	6.57	1.03	0.91

Stage 2 Participant Details for the Division, Addition and Subtraction Experiments

Additional Key:

CA = mean chronological age of participants (in months) over mathematical testing period.

Table A.10 Young dyslexics

Participant number	*CA*	*CA*	*SS*	*MS*	*BDT*	*BDT**
D1	133	136	27	45	8.0	6.0
D2	120	124	28	39	10.0	8.0
D3	114	118	23	39	6.5	4.5
D4	133	134	22	40	7.5	5.5
D5	117	117	20	34	8.0	6.0
D6	134	134	16	42	7.0	5.5
D7	121	121	28	54	4.5	3.5
D8	131	132	32	41	7.0	5.0
D9	134	135	45	39	6.0	4.0
D10	130	132	43	51	5.0	3.5
Group mean	126.7	128.3	28.4	42.4	6.95	5.15
Standard deviation	7.80	7.47	9.42	6.04	1.59	1.38

Table A.11 Medium-age dyslexics

Participant number	*CA*	*CA*	*SS*	*MS*	*BDT*	*BDT**
D11	150	154	31	49	7.0	5.0
D12	154	158	55	50	5.0	4.5
D13	147	147	31	50	8.0	6.5
D14	146	146	37	46	7.0	5.0
D15	145	146	37	50	6.5	5.5
D16	152	153	29	50	7.0	5.5
D17	142	143	47	50	4.5	3.5
D18	152	153	31	46	8.5	6.5
D19	144	144	55	55	4.5	3.5
D20	141	142	51	48	5.0	4.0
Group mean	147.3	148.6	40.4	49.4	6.3	4.95
Standard deviation	4.50	5.46	10.54	2.55	1.46	1.09

Table A.12 Old dyslexics

Participant number	*CA*	*CA*	*SS*	*MS*	*BDT*	*BDT**
D21	183	183	55	51	7.0	5.5
D22	174	174	54	49	6.0	5.0
D23	174	174	56	50	4.5	3.5
D24	181	181	49	51	6.0	5.0
D25	180	180	17	56	7.0	5.5
D26	178	181	54	54	6.5	5.0
D27	170	170	72	56	4.5	3.5
D28	172	176	67	43	6.0	4.0
D29	179	179	72	53	4.5	4.0
D30	180	183	64	49	5.5	4.5
Group mean	177.1	178.1	56	51.2	5.75	4.55
Standard deviation	4.31	4.38	15.90	3.88	0.98	0.76

Table A.13 Young controls

Participant number	*CA*	*CA*	*SS*	*MS*	*BDT*	*BDT**
C1	132	136	61	44	3.0	2.5
C2	123	123	65	39	1.5	1.0
C3	116	116	62	40	3.0	2.5
C4	127	131	72	38	2.0	1.5
C5	114	114	53	35	2.5	1.5
C6	132	133	58	34	2.5	2.5
C7	116	121	76	47	2.5	0.5
C8	124	129	64	37	0	0
C9	133	134	83	38	1.5	1.0
C10	130	134	75	45	2.0	1.5
Group mean	124.7	127.1	66.9	39.7	2.05	1.45
Standard deviation	7.29	8.01	9.29	4.32	0.90	0.86

Table A.14 Medium controls

Participant number	*CA*	*CA*	*SS*	*MS*	*BDT*	*BDT**
C11	152	152	90	48	1.5	1.0
C12	150	154	81	46	2.0	1.5
C13	140	144	90	47	0	0
C14	142	146	69	41	3.0	1.5
C15	144	144	76	46	2.0	1.5
C16	148	151	84	46	1.5	1.5
C17	135	139	68	45	1.5	0.5
C18	147	151	80	42	1.5	0.5
C19	138	141	69	41	3.0	2.0
C20	137	138	87	43	2.0	1.0
Group mean	143.3	146	79.4	44.5	1.8	1.1
Standard deviation	5.83	5.73	8.59	2.55	0.86	0.61

Table A.15 Old controls

Participant number	*CA*	*CA*	*SS*	*MS*	*BDT*	*BDT**
C21	180	180	93	51	1.5	0.5
C22	170	170	90	46	2.5	2.5
C23	173	175	82	52	2.0	1.0
C24	180	182	88	49	2.5	2.5
C25	177	179	85	50	3.0	2.0
C26	176	178	89	52	2.5	2.0
C27	172	172	81	52	3.0	2.0
C28	175	176	89	43	2.5	2.5
C29	178	180	89	45	3.0	2.0
C30	181	181	90	41	2.0	2.0
Group mean	176.2	177.3	87.6	48.1	2.45	1.9
Standard deviation	3.71	3.97	3.78	4.07	0.50	0.66

APPENDIX B

Multiplication

Table B.1 Question order for Multiplication

Question number	*Question*	*Question number*	*Question*	*Question number*	*Question*	*Question number*	*Question*
1	4 × 7	37	11 × 9	73	3 × 4	109	1 × 8
2	8 × 10	38	5 × 1	74	6 × 7	110	9 × 5
3	5 × 9	39	3 × 8	75	10 × 11	111	7 × 6
4	6 × 8	40	5 × 5	76	8 × 2	112	4 × 9
5	6 × 1	41	4 × 11	77	4 × 10	113	10 × 2
6	3 × 2	42	8 × 12	78	11 × 10	114	3 × 1
7	6 × 5	43	4 × 1	79	1 × 12	115	7 × 12
8	9 × 1	44	3 ×x 9	80	12 × 8	116	9 × 12
9	5 × 2	45	7 × 10	81	3 × 12	117	7 × 1
10	3 × 11	46	1 × 6	82	11 × 7	118	1 × 11
11	12 × 11	47	9 × 6	83	7 × 1	119	5 × 3
12	5 × 8	48	2 × 11	84	3 × 5	120	10 × 8
13	2 × 4	49	9 × 2	85	2 × 6	121	3 × 10
14	7 × 3	50	5 × 11	86	7 × 8	122	8 × 9
15	11 × 6	51	5 × 12	87	8 × 4	123	9 × 10
16	11 × 2	52	6 × 2	88	4 × 3	124	6 × 6
17	10 × 9	53	10 × 12	89	1 × 1	125	10 × 4
18	6 × 9	54	4 × 5	90	8 × 8	126	2 × 12
19	7 × 5	55	2 × 3	91	1 × 2	127	8 × 1
20	9 × 3	56	10 × 3	92	10 × 7	128	2 × 5
21	5 × 10	57	2 × 10	93	12 × 1	129	5 × 7
22	3 × 3	58	12 × 6	94	10 × 5	130	8 × 3
23	9 × 8	59	4 × 6	95	1 × 4	131	6 × 1
24	2 × 2	60	7 × 2	96	6 × 4	132	8 × 7
25	11 × 8	61	9 × 9	97	8 × 5	133	1 × 7
26	4 × 12	62	6 × 12	98	12 × 7	134	11 × 11
27	2 × 8	63	4 × 2	99	7 × 7	135	5 × 6
28	1 × 3	64	4 × 8	100	12 × 3	136	3 × 7
29	9 × 7	65	1 × 4	101	12 × 2	137	10 × 10
30	6 × 3	66	12 × 2	102	12 × 4	138	5 × 4
31	12 × 5	67	9 × 4	103	11 × 12	139	11 × 1
32	10 × 6	68	3 × 6	104	9 × 1	140	2 × 9
33	12 ×10	69	7 × 4	105	11 × 5	141	2 × 7
34	12 × 9	70	1 × 3	106	2 × 1	142	8 × 6
35	10 × 1	71	8 × 1	107	4 × 4	143	1 × 5
36	7 × 9	72	1 × 10	108	1 × 9	144	6 × 10

INTERVAL

APPENDIX C

Division

Table C.1 Question order for Division

Question number	*Question*	*Question number*	*Question*	*Question number*	*Question*	*Question number*	*Question*
1	108 ÷ 9	37	54 ÷ 6	73	36 ÷ 6	109	66 ÷ 6
2	25 ÷ 5	38	22 ÷ 2	74	14 ÷ 2	110	40 ÷ 10
3	96 ÷ 12	39	120 ÷ 10	75	16 ÷ 8	111	27 ÷ 3
4	15 ÷ 5	40	55 ÷ 11	76	40 ÷ 5	112	36 ÷ 9
5	24 ÷ 2	41	4 ÷ 4	77	8 ÷ 2	113	10 ÷ 5
6	50 ÷ 5	42	35 ÷ 7	78	60 ÷ 6	114	56 ÷ 7
7	30 ÷ 6	43	16 ÷ 4	79	24 ÷ 3	115	44 ÷ 11
8	5 ÷ 1	44	55 ÷ 5	80	2 ÷ 2	116	18 ÷ 2
9	30 ÷ 5	45	60 ÷ 5	81	30 ÷ 3	117	60 ÷ 12
10	72 ÷ 6	46	28 ÷ 4	82	90 ÷ 10	118	8 ÷ 1
11	2 ÷ 1	47	99 ÷ 11	83	36 ÷ 3	119	21 ÷ 7
12	33 ÷ 3	48	12 ÷ 4	84	10 ÷ 1	120	72 ÷ 8
13	8 ÷ 8	49	5 ÷ 5	85	24 ÷ 4	121	84 ÷ 7
14	45 ÷ 9	50	132 ÷ 11	86	110 ÷ 11	122	12 ÷ 2
15	10 ÷ 10	51	72 ÷ 12	87	18 ÷ 3	123	3 ÷ 3
16	45 ÷ 5	52	88 ÷ 11	88	30 ÷ 10	124	35 ÷ 5
17	110 ÷ 10	53	63 ÷ 9	89	56 ÷ 8	125	6 ÷ 2
18	6 ÷ 3	54	22 ÷ 11	90	24 ÷ 6	126	77 ÷ 11
19	100 ÷ 10	55	48 ÷ 8	91	27 ÷ 9	127	20 ÷ 4
20	1 ÷ 1	56	81 ÷ 9	92	64 ÷ 8	128	42 ÷ 6
21	144 ÷ 12	57	42 ÷ 7	93	7 ÷ 1	129	4 ÷ 1
22	99 ÷ 9	58	80 ÷ 8	94	32 ÷ 4	130	15 ÷ 3
23	48 ÷ 4	59	121 ÷ 11	95	20 ÷ 5	131	12 ÷ 6
24	3 ÷ 1	60	84 ÷ 12	96	9 ÷ 3	132	21 ÷ 3
25	20 ÷ 2	61	96 ÷ 8	97	54 ÷ 9	133	40 ÷ 8
26	132 ÷ 12	62	70 ÷ 7	98	20 ÷ 10	134	18 ÷ 9
27	40 ÷ 4	63	33 ÷ 11	99	6 ÷ 6	135	11 ÷ 11
28	6 ÷ 1	64	7 ÷ 7	100	14 ÷ 7	136	108 ÷ 12
29	88 ÷ 8	65	18 ÷ 6	101	12 ÷ 3	137	66 ÷ 11
30	10 ÷ 2	66	44 ÷ 4	102	48 ÷ 6	138	48 ÷ 12
31	32 ÷ 8	67	120 ÷ 12	103	9 ÷ 9	139	50 ÷ 10
32	9 ÷ 1	68	11 ÷ 1	104	24 ÷ 8	140	24 ÷ 12
33	4 ÷ 2	69	12 ÷ 12	105	49 ÷ 7	141	72 ÷ 9
34	36 ÷ 4	70	63 ÷ 7	106	77 ÷ 7	142	28 ÷ 7
35	90 ÷ 9	71	70 ÷ 10	107	36 ÷ 12	143	60 ÷ 10
36	16 ÷ 2	72	12 ÷ 1	108	80 ÷ 10	144	8 ÷ 4

INTERVAL

APPENDIX D

Addition

Table D.1 Addition questions within each category

Category 1 LN	*Category 2 HN*	*Category 3 LC*	*Category 4 HC*	*Category 5 HARD*
47 + 2	92 + 6	29 + 2	37 + 6	65 + 26
81 + 3	62 + 7	68 + 3	45 + 7	26 + 57
61 + 4	51 + 8	89 + 4	73 + 8	35 + 28
81 + 2	52 + 6	79 + 2	35 + 6	28 + 36
32 + 3	21 + 7	58 + 3	74 + 7	49 + 37
92 + 4	71 + 8	47 + 4	84 + 8	57 + 38
73 + 2	32 + 6	49 + 2	45 + 6	37 + 46
64 + 3	42 + 7	39 + 3	65 + 7	24 + 47
32 + 4	81 + 8	28 + 4	54 + 8	23 + 48
54 + 2	73 + 6	59 + 2	47 + 6	37 + 56
75 + 3	51 + 7	28 + 3	46 + 7	48 + 37
45 + 4	41 + 8	79 + 4	86 + 8	24 + 58
36 + 2	62 + 6	39 + 2	68 + 6	59 + 26
56 + 3	32 + 7	48 + 3	38 + 7	25 + 67
23 + 4	31 + 8	67 + 4	29 + 8	26 + 68

(Not in the order presented in the Main Experiment)

Table D.2 Question order for Addition

Question number	*Question*	*Category*	*Question number*	*Question*	*Category*	*Question number*	*Question*	*Category*
1	21 + 7	2	26	39 + 3	3	51	81 + 8	2
2	47 + 2	1	27	32 + 6	2	52	29 + 2	3
3	62 + 6	2	28	45 + 7	4	53	42 + 7	2
4	74 + 7	4	29	58 + 3	3	54	35 + 6	4
5	31 + 8	2	30	73 + 6	2	55	48 + 37	5
6	45 + 6	4	31	59 + 2	3	56	47 + 4	3
7	71 + 8	2	32	32 + 3	1	57	39 + 2	3
8	28 + 36	5	33	29 + 8	3	58	35 + 28	5
9	45 + 4	1	34	25 + 67	5	59	52 + 6	2
10	79 + 2	3	35	51 + 8	2	60	86 + 8	4
11	23 + 4	1	36	49 + 2	3	61	62 + 7	2
12	37 + 46	5	37	68 + 6	4	62	28 + 4	3
13	54 + 2	1	38	32 + 7	2	63	37 + 6	4
14	75 + 3	1	39	49 + 37	5	64	68 + 3	3
15	46 + 7	4	40	67 + 4	3	65	81 + 2	1
16	73 + 8	4	41	92 + 6	2	66	59 + 26	5
17	51 + 7	2	42	37 + 56	5	67	24 + 47	5
18	26 + 68	5	43	41 + 8	2	68	81 + 3	1
19	79 + 4	3	44	65 + 7	4	69	65 + 26	5
20	54 + 8	4	45	48 + 3	3	70	89 + 4	3
21	28 + 3	3	46	92 + 4	1	71	24 + 58	5
22	36 + 2	1	47	73 + 2	1	72	56 + 3	1
23	61 + 4	1	48	26 + 57	5	73	23 + 48	5
24	84 + 8	4	49	32 + 4	1	74	38 + 7	4
25	47 + 6	4	50	57 + 38	5	75	64 + 3	1

APPENDIX E

Subtraction

Table E.1 Subtraction questions within each category

Category 1 LN	*Category 2 HN*	*Category 3 LC*	*Category 4 HC*	*Category 5 HARD*
29 – 2	87 – 6	31 – 2	95 – 6	51 – 26
24 – 3	78 – 7	41 – 3	81 – 7	61 – 27
35 – 4	69 – 8	53 – 4	67 – 8	71 – 28
38 – 2	58 – 6	61 – 2	74 – 6	82 – 56
45 – 3	49 – 7	72 – 3	45 – 7	92 – 47
46 – 4	39 – 8	82 – 4	56 – 8	52 – 28
54 – 2	29 – 6	91 – 2	93 – 6	63 – 36
56 – 3	98 – 7	31 – 3	54 – 7	75 – 37
67 – 4	89 – 8	41 – 4	75 – 8	83 – 48
65 – 2	37 – 6	51 – 2	62 – 6	94 – 56
78 – 3	69 – 7	62 – 3	53 – 7	54 – 27
79 – 4	59 – 8	71 – 4	34 – 8	95 – 58
86 – 2	48 – 6	81 – 2	41 – 6	75 – 46
87 – 3	39 – 7	92 – 3	52 – 7	86 – 37
98 – 4	29 – 8	42 – 4	73 – 8	97 – 68

(Not in the order presented in the Main Experiment)

Table E.2 Question order for Subtraction

Question number	*Question*	*Category*	*Question number*	*Question*	*Category*	*Question number*	*Question*	*Category*
1	52 – 7	4	26	98 – 7	2	51	72 – 3	3
2	35 – 4	1	27	62 – 6	4	52	58 – 6	2
3	81 – 7	4	28	89 – 8	2	53	41 – 4	3
4	74 – 6	4	29	75 – 46	5	54	87 – 6	2
5	91 – 2	3	30	86 – 2	1	55	34 – 8	4
6	94 – 56	5	31	69 – 7	2	56	82 – 4	3
7	31 – 2	3	32	42 – 4	3	57	63 – 36	5
8	67 – 4	1	33	29 – 2	1	58	56 – 8	4
9	41 – 3	3	34	53 – 7	4	59	78 – 3	1
10	54 – 2	1	35	69 – 8	2	60	95 – 6	4
11	83 – 48	5	36	45 – 7	4	61	39 – 7	2
12	78 – 7	2	37	24 – 3	1	62	52 – 28	5
13	67 – 8	4	38	92 – 47	5	63	37 – 6	2
14	31 – 3	3	39	56 – 3	1	64	75 – 8	4
15	98 – 4	1	40	49 – 7	2	65	62 – 3	3
16	61 – 2	3	41	81 – 2	3	66	48 – 6	2
17	82 – 56	5	42	93 – 6	4	67	71 – 4	3
18	53 – 4	3	43	71 – 28	5	68	45 – 3	1
19	39 – 8	2	44	59 – 8	2	69	97 – 68	5
20	86 – 37	5	45	65 – 2	1	70	54 – 7	4
21	41 – 6	4	46	75 – 37	5	71	38 – 2	1
22	92 – 3	3	47	29 – 6	2	72	29 – 8	2
23	54 – 27	5	48	87 – 3	1	73	61 – 27	5
24	79 – 4	1	49	46 – 4	1	74	73 – 8	4
25	51 – 2	3	50	95 – 58	5	75	51 – 26	5

APPENDIX F

Instructions for the Simple Reaction Time Test

After his name and age in years and months had been typed into the computer by the experimenter, the participant was given the following instructions:

(1) 'This is a REACTION TIME TEST to see how quickly you can respond to a star which will appear on the screen here [experimenter points to the centre of the screen]. When you see a star, press the "Enter" key.'

(2) 'Watch out, because a star will come up on the screen several times. Sometimes there will be quite a long gap between one star and the next. Sometimes they may come quickly straight after each other - so be prepared.'

(3) 'When you see a star, you IMMEDIATELY press the "Enter" key. We are timing how quickly you see the star, so you press the "Enter" key to show us that you have seen the star.'

(4) 'You press the "Enter" key once per star. Press once clearly and sensibly. Do not press the "Enter" key twice for a star and do not hold the "Enter" key down.'

(6) 'Have your finger hovering over the "Enter" key so that you are ready to press it immediately you see a star.'

(6) Press the "Enter" key to start the experiment when I say, ready, steady, go.'

APPENDIX F1

Anova Tables for Correctness on Multiplication

Univariate Analysis of Variance

Between-Subjects Factors

		Value Label	N
Subject Group	1.00	Dyslexic	30
	2.00	Control Age	30
	3.00	Control Spelling	30
Age of Subjects	1.00	Young	30
	2.00	Medium	30
	3.00	Old	30

Descriptive Statistics

Dependent Variable: Proportion Correct

Subject Group	Age of Subjects	Mean	Std. Deviation	N
Dyslexic	Young	.62150	.161675	10
	Medium	.84830	.072299	10
	Old	.88000	.046795	10
	Total	.78327	.155314	30
Control Age	Young	.85170	.087215	10
	Medium	.91270	.032891	10
	Old	.94610	.019226	10
	Total	.90350	.066267	30
Control Spelling	Young	.48410	.225590	10
	Medium	.78150	.172277	10
	Old	.83790	.087078	10
	Total	.70117	.228643	30
Total	Young	.65243	.223740	30
	Medium	.84750	.118899	30
	Old	.88800	.072105	30
	Total	.79598	.182501	90

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Proportion Correct

F	df1	df2	Sig.
6.402	8	81	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+GROUP+AGE+GROUP * AGE

Tests of Between-Subjects Effects

Dependent Variable: Proportion Correct

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.787[a]	8	.223	15.377	.000	.603
Intercept	57.022	1	57.022	3924.550	.000	.980
GROUP	.621	2	.311	21.382	.000	.346
AGE	.952	2	.476	32.755	.000	.447
GROUP * AGE	.214	4	5.356E-02	3.686	.008	.154
Error	1.177	81	1.453E-02			
Total	59.987	90				
Corrected Total	2.964	89				

a. R Squared = .603 (Adjusted R Squared = .564)

Lack of Fit Tests

Dependent Variable: Proportion Correct

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Lack of Fit	.000	0	.	.	.	.000
Pure Error	1.177	81	.015			

Estimated Marginal Means

1. Grand Mean

Dependent Variable: Proportion Correct

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.796	.013	.771	.821

2. Subject Group

Dependent Variable: Proportion Correct

Subject Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Dyslexic	.783	.022	.739	.827
Control Age	.903	.022	.860	.947
Control Spelling	.701	.022	.657	.745

3. Age of Subjects

Dependent Variable: Proportion Correct

Age of Subjects	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Young	.652	.022	.609	.696
Medium	.848	.022	.804	.891
Old	.888	.022	.844	.932

4. Subject Group * Age of Subjects

Dependent Variable: Proportion Correct

Subject Group	Age of Subjects	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Dyslexic	Young	.621	.038	.546	.697
	Medium	.848	.038	.772	.924
	Old	.880	.038	.804	.956
Control Age	Young	.852	.038	.776	.928
	Medium	.913	.038	.837	.989
	Old	.946	.038	.870	1.022
Control Spelling	Young	.484	.038	.408	.560
	Medium	.782	.038	.706	.857
	Old	.838	.038	.762	.914

APPENDIX F2

Anova Tables for Correctness on Division

Univariate Analysis of Variance

Warnings

Post hoc tests are not performed for Experimental or Control Group because there are fewer than three groups.

Between-Subjects Factors

		Value Label	N
Age Band of Subjects	1	Young	20
	2	Medium	20
	3	Old	20
Experimental or Control Group	0	Control	30
	1	Dyslexic	30

Descriptive Statistics

Dependent Variable: DDNTOT

Age Band of Subjects	Experimental or Control	Mean	Std. Deviation	N
Young	Control	120.0000	13.39983	10
	Dyslexic	75.3000	32.78228	10
	Total	97.6500	33.46526	20
Medium	Control	130.5000	11.22745	10
	Dyslexic	121.0000	12.35584	10
	Total	125.7500	12.48104	20
Old	Control	134.3000	5.53875	10
	Dyslexic	118.6000	18.69759	10
	Total	126.4500	15.65239	20
Total	Control	128.2667	11.92486	30
	Dyslexic	104.9667	30.75093	30
	Total	116.6167	25.93675	60

Levene's Test of Equality of Error Variances[a]

Dependent Variable: DDNTOT

F	df1	df2	Sig.
4.538	5	54	.002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+AGE+GROUP+AGE * GROUP

Tests of Between-Subjects Effects

Dependent Variable: DDNTOT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	22471.083[a]	5	4494.217	14.094	.000
Intercept	815966.817	1	815966.817	2558.915	.000
AGE	10796.933	2	5398.467	16.930	.000
GROUP	8143.350	1	8143.350	25.538	.000
AGE * GROUP	3530.800	2	1765.400	5.536	.006
Error	17219.100	54	318.872		
Total	855657.000	60			
Corrected Total	39690.183	59			

a. *R Squared = .566 (Adjusted R Squared = .526)*

Lack of Fit Tests

Dependent Variable: DDNTOT

Source	Sum of Squares	df	Mean Square	F	Sig.
Lack of Fit	.000	0	.	.	.
Pure Error	17219.100	54	318.872		

Estimated Marginal Means

1. Grand Mean

Dependent Variable: DDNTOT

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
116.617	2.305	111.995	121.239

2. Age Band of Subjects

Dependent Variable: DDNTOT

Age Band of Subjects	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Young	97.650	3.993	89.645	105.655
Medium	125.750	3.993	117.745	133.755
Old	126.450	3.993	118.445	134.455

3. Experimental or Control Group

Dependent Variable: DDNTOT

Experimental or Control Group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Control	128.267	3.260	121.730	134.803
Dyslexic	104.967	3.260	98.430	111.503

4. Age Band of Subjects * Experimental or Control Group

Dependent Variable: DDNTOT

Age Band of Subjects	Experimental or Control Group	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Young	Control	120.000	5.647	108.679	131.321
	Dyslexic	75.300	5.647	63.979	86.621
Medium	Control	130.500	5.647	119.179	141.821
	Dyslexic	121.000	5.647	109.679	132.321
Old	Control	134.300	5.647	122.979	145.621
	Dyslexic	118.600	5.647	107.279	129.921

APPENDIX F3

Anova Tables for Correctness on Addition

Univariate Analysis of Variance

Warnings

Post hoc tests are not performed for Experimental or Control Group because there are fewer than three groups.

Between-Subjects Factors

		Value Label	N
Experimental or Control Group	0	Control	30
	1	Dyslexic	30
Age Band of Subjects	1	Young	20
	2	Medium	20
	3	Old	20

Descriptive Statistics

Dependent Variable: TOTALADD

Experimental or	Age Band of Subjects	Mean	Std. Deviation	N
Control	Young	.9020	6.830E-02	10
	Medium	.9260	5.765E-02	10
	Old	.9460	2.905E-02	10
	Total	.9247	5.470E-02	30
Dyslexic	Young	.7073	.1747	10
	Medium	.9213	4.272E-02	10
	Old	.9193	3.711E-02	10
	Total	.8493	.1446	30
Total	Young	.8047	.1628	20
	Medium	.9237	4.944E-02	20
	Old	.9327	3.520E-02	20
	Total	.8870	.1148	60

Levene's Test of Equality of Error Variances[a]

Dependent Variable: TOTALADD

F	df1	df2	Sig.
8.407	5	54	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+GROUP+AGE+GROUP * AGE

Tests of Between-Subjects Effects

Dependent Variable: TOTALADD

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	.397[a]	5	7.946E-02	11.275	.000	.511
Intercept	47.206	1	47.206	6697.822	.000	.992
GROUP	8.513E-02	1	8.513E-02	12.078	.001	.183
AGE	.204	2	.102	14.485	.000	.349
GROUP * AGE	.108	2	5.401E-02	7.663	.001	.221
Error	.381	54	7.048E-03			
Total	47.984	60				
Corrected Total	.778	59				

a. R Squared = .511 (Adjusted R Squared = .465)

Estimated Marginal Means

1. Grand Mean

Dependent Variable: TOTALADD

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.887	.011	.865	.909

2. Experimental or Control Group

Estimates

Dependent Variable: TOTALADD

Experimental or Control Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Control	.925	.015	.894	.955
Dyslexic	.849	.015	.819	.880

Pairwise Comparisons

Dependent Variable: TOTALADD

(I) Experimental or Control Group	(J) Experimental or Control Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Control	Dyslexic	7.533E-02*	.022	.001	3.187E-02	.119
Dyslexic	Control	-7.533E-02*	.022	.001	-.119	-3.187E-02

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: TOTALADD

	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Contrast	8.513E-02	1	8.513E-02	12.078	.001	.183
Error	.381	54	7.048E-03			

The F tests the effect of Experimental or Control Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Age Band of Subjects

Estimates

Dependent Variable: TOTALADD

Age Band of Subjects	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Young	.805	.019	.767	.842
Medium	.924	.019	.886	.961
Old	.933	.019	.895	.970

Pairwise Comparisons

Dependent Variable: TOTALADD

(I) Age Band of Subjects	(J) Age Band of Subjects	Mean Difference (I-J)	Std. Error	Sig.[a]
Young	Medium	-.119*	.027	.000
	Old	-.128*	.027	.000
Medium	Young	.119*	.027	.000
	Old	-9.000E-03	.027	.736
Old	Young	.128*	.027	.000
	Medium	9.000E-03	.027	.736

Based on estimated marginal means

Pairwise Comparisons

Dependent Variable: TOTALADD

(I) Age Band of Subjects	(J) Age Band of Subjects	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Young	Medium	-.172	-6.577E-02
	Old	-.181	-7.477E-02
Medium	Young	6.577E-02	.172
	Old	-6.223E-02	4.423E-02
Old	Young	7.477E-02	.181
	Medium	-4.423E-02	6.223E-02

Based on estimated marginal means

*. *The mean difference is significant at the .05 level.*

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: TOTALADD

	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Contrast	*.204*	*2*	*.102*	*14.485*	*.000*	*.349*
Error	.381	54	7.048E-03			

The F tests the effect of Age Band of Subjects. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

4. Experimental or Control Group * Age Band of Subjects

Dependent Variable: TOTALADD

Experimental or Control Group	Age Band of Subjects	Mean	Std. Error	*95% Confidence Interval* Lower Bound	Upper Bound
Control	Young	.902	.027	.849	.955
	Medium	.926	.027	.873	.979
	Old	.946	.027	.893	.999
Dyslexic	Young	.707	.027	.654	.761
	Medium	.921	.027	.868	.975
	Old	.919	.027	.866	.973

APPENDIX F4

Anova Tables for Correctness on Subtraction

Univariate Analysis of Variance

Warnings

Post hoc tests are not performed for Experimental or Control Group because there are fewer than three groups.

Between-Subjects Factors

		Value Label	N
Experimental or Control Group	0	Control	30
	1	Dyslexic	30
Age Band of Subjects	1	Young	20
	2	Medium	20
	3	Old	20

Descriptive Statistics

Dependent Variable: TOTALSUB

Experimental or	Age Band of Subjects	Mean	Std. Deviation	N
Control	Young	.7960	9.909E-02	10
	Medium	.8627	.1035	10
	Old	.9193	5.178E-02	10
	Total	.8593	9.917E-02	30
Dyslexic	Young	.5167	.1753	10
	Medium	.8620	9.646E-02	10
	Old	.8493	.1031	10
	Total	.7427	.2054	30
Total	Young	.6563	.1993	20
	Medium	.8623	9.739E-02	20
	Old	.8843	8.715E-02	20
	Total	.8010	.1704	60

Levene's Test of Equality of Error Variances[a]

Dependent Variable: TOTALSUB

F	df1	df2	Sig.
1.773	5	54	.134

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. *Design: Intercept+GROUP+AGE+GROUP * AGE*

Tests of Between-Subjects Effects

Dependent Variable: TOTALSUB

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	1.047[a]	5	.209	17.011	.000	.612
Intercept	38.496	1	38.496	3126.372	.000	.983
GROUP	.204	1	.204	16.581	.000	.235
AGE	.633	2	.316	25.691	.000	.488
GROUP * AGE	.210	2	.105	8.546	.001	.240
Error	.665	54	1.231E-02			
Total	40.208	60				
Corrected Total	1.712	59				

a. R Squared = .612 (Adjusted R Squared = .576)

Estimated Marginal Means

1. Grand Mean

Dependent Variable: TOTALSUB

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.801	.014	.772	.830

2. Experimental or Control Group

Estimates

Dependent Variable: TOTALSUB

Experimental or Control Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Control	.859	.020	.819	.900
Dyslexic	.743	.020	.702	.783

Pairwise Comparisons

Dependent Variable: TOTALSUB

(I) Experimental or Control Group	(J) Experimental or Control Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Control	Dyslexic	.117*	.029	.000	5.922E-02	.174
Dyslexic	Control	-.117*	.029	.000	-.174	-5.922E-02

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: TOTALSUB

	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Contrast	.204	1	.204	16.581	.000	.235
Error	.665	54	1.231E-02			

The F tests the effect of Experimental or Control Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Age Band of Subjects

Estimates

Dependent Variable: TOTALSUB

Age Band of Subjects	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Young	.656	.025	.607	.706
Medium	.862	.025	.813	.912
Old	.884	.025	.835	.934

Pairwise Comparisons

Dependent Variable: TOTALSUB

(I) Age Band of Subjects	(J) Age Band of Subjects	Mean Difference (I-J)	Std. Error	Sig.[a]
Young	Medium	-.206*	.035	.000
	Old	-.228*	.035	.000
Medium	Young	.206*	.035	.000
	Old	-2.200E-02	.035	.533
Old	Young	.228*	.035	.000
	Medium	2.200E-02	.035	.533

Based on estimated marginal means

Pairwise Comparisons

Dependent Variable: TOTALSUB

(I) Age Band of Subjects	(J) Age Band of Subjects	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Young	Medium	-.276	-.136
	Old	-.298	-.158
Medium	Young	.136	.276
	Old	-9.235E-02	4.835E-02
Old	Young	.158	.298
	Medium	-4.835E-02	9.235E-02

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: TOTALSUB

	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Contrast	.633	2	.316	25.691	.000	.488
Error	.665	54	1.231E-02			

The F tests the effect of Age Band of Subjects. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

4. Experimental or Control Group * Age Band of Subjects

Dependent Variable: TOTALSUB

Experimental or Control Group	Age Band of Subjects	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Control	Young	.796	.035	.726	.866
	Medium	.863	.035	.792	.933
	Old	.919	.035	.849	.990
Dyslexic	Young	.517	.035	.446	.587
	Medium	.862	.035	.792	.932
	Old	.849	.035	.779	.920

APPENDIX F5

Anova Tables for Speed of Multiplication

Univariate Analysis of Variance

Between-Subjects Factors

		Value Label	N
Subject Group	1.00	Dyslexic	30
	2.00	Control Age	30
	3.00	Control Spelling	30
Age of Subjects	1.00	Young	30
	2.00	Medium	30
	3.00	Old	30

Descriptive Statistics

Dependent Variable: Response Time in Seconds

Subject Group	Age of Subjects	Mean	Std. Deviation	N
Dyslexic	Young	13.0170	3.04232	10
	Medium	7.9270	2.60443	10
	Old	5.7650	1.15505	10
	Total	8.9030	3.86676	30
Control Age	Young	7.7460	1.89480	10
	Medium	5.4520	1.11005	10
	Old	3.7020	.61937	10
	Total	5.6333	2.11006	30
Control Spelling	Young	15.1350	3.83182	10
	Medium	9.2400	3.38995	10
	Old	7.6110	1.77441	10
	Total	10.6620	4.46168	30
Total	Young	11.9660	4.30443	30
	Medium	7.5397	2.93351	30
	Old	5.6927	2.03653	30
	Total	8.3994	4.14720	90

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Response Time in Seconds

F	df1	df2	Sig.
4.263	8	81	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+GROUP+AGE+GROUP * AGE

Tests of Between-Subjects Effects

Dependent Variable: Response Time in Seconds

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1063.616[a]	8	132.952	23.054	.000	.695
Intercept	6349.560	1	6349.560	1101.036	.000	.931
GROUP	390.723	2	195.361	33.876	.000	.455
AGE	623.585	2	311.793	54.066	.000	.572
GROUP * AGE	49.308	4	12.327	2.138	.084	.095
Error	467.119	81	5.767			
Total	7880.295	90				
Corrected Total	1530.735	89				

a. R Squared = .695 (Adjusted R Squared = .665)

Lack of Fit Tests

Dependent Variable: Response Time in Seconds

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Lack of Fit	.000	0	.	.	.	.000
Pure Error	467.119	81	5.767			

Estimated Marginal Means

1. Grand Mean

Dependent Variable: Response Time in Seconds

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
8.399	.253	7.896	8.903

2. Subject Group

Dependent Variable: Response Time in Seconds

Subject Group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Dyslexic	8.903	.438	8.031	9.775
Control Age	5.633	.438	4.761	6.506
Control Spelling	10.662	.438	9.790	11.534

3. Age of Subjects

Dependent Variable: Response Time in Seconds

Age of Subjects	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Young	11.966	.438	11.094	12.838
Medium	7.540	.438	6.667	8.412
Old	5.693	.438	4.820	6.565

4. Subject Group * Age of Subjects

Dependent Variable: Response Time in Seconds

Subject Group	Age of Subjects	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Dyslexic	Young	13.017	.759	11.506	14.528
	Medium	7.927	.759	6.416	9.438
	Old	5.765	.759	4.254	7.276
Control Age	Young	7.746	.759	6.235	9.257
	Medium	5.452	.759	3.941	6.963
	Old	3.702	.759	2.191	5.213
Control Spelling	Young	15.135	.759	13.624	16.646
	Medium	9.240	.759	7.729	10.751
	Old	7.611	.759	6.100	9.122

APPENDIX F6

Anova Tables for Speed of Division

Univariate Analysis of Variance

Warnings

Post hoc tests are not performed for Experimental or Control Group because there are fewer than three groups.

Between-Subjects Factors

		Value Label	N
Experimental or Control Group	0	Control	30
	1	Dyslexic	30
Age Band of Subjects	1	Young	20
	2	Medium	20
	3	Old	20

Descriptive Statistics

Dependent Variable: Unfiltered RT Ave

Experimental or Control	Age Band of Subjects	Mean	Std. Deviation	N
Control	Young	7.6920	2.08325	10
	Medium	5.6741	2.06308	10
	Old	4.5473	.94313	10
	Total	5.9712	2.16668	30
Dyslexic	Young	13.9045	3.65135	10
	Medium	7.9147	2.51156	10
	Old	7.5841	2.76295	10
	Total	9.8011	4.14638	30
Total	Young	10.7983	4.30436	20
	Medium	6.7944	2.51498	20
	Old	6.0657	2.54251	20
	Total	7.8861	3.80621	60

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Unfiltered RT Ave

F	df1	df2	Sig.
2.453	5	54	.045

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+GROUP+AGE+GROUP * AGE

Tests of Between-Subjects Effects

Dependent Variable: Unfiltered RT Ave

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	523.909[a]	5	104.782	17.103	.000
Intercept	3731.455	1	3731.455	609.054	.000
GROUP	220.026	1	220.026	35.913	.000
AGE	259.725	2	129.862	21.196	.000
GROUP * AGE	44.158	2	22.079	3.604	.034
Error	330.839	54	6.127		
Total	4586.203	60			
Corrected Total	854.748	59			

a. R Squared = .613 (Adjusted R Squared = .577)

Lack of Fit Tests

Dependent Variable: Unfiltered RT Ave

Source	Sum of Squares	df	Mean Square	F	Sig.
Lack of Fit	.000	0	.	.	.
Pure Error	330.839	54	6.127		

Estimated Marginal Means

1. Grand Mean

Dependent Variable: Unfiltered RT Ave

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
7.886	.320	7.245	8.527

2. Experimental or Control Group

Estimates

Dependent Variable: Unfiltered RT Ave

Experimental or Control Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Control	5.971	.452	5.065	6.877
Dyslexic	9.801	.452	8.895	10.707

Pairwise Comparisons

Dependent Variable: Unfiltered RT Ave

(I) Experimental or Control Group	(J) Experimental or Control Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Control	Dyslexic	-3.830*	.639	.000	-5.111	-2.549
Dyslexic	Control	3.830*	.639	.000	2.549	5.111

Based on estimated marginal means

*. *The mean difference is significant at the .05 level.*

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Unfiltered RT Ave

	Sum of Squares	df	Mean Square	F	Sig.
Contrast	220.026	1	220.026	35.913	.000
Error	330.839	54	6.127		

The F tests the effect of Experimental or Control Group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Age Band of Subjects

Estimates

Dependent Variable: Unfiltered RT Ave

Age Band of Subjects	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Young	10.798	.553	9.689	11.908
Medium	6.794	.553	5.685	7.904
Old	6.066	.553	4.956	7.175

Pairwise Comparisons

Dependent Variable: Unfiltered RT Ave

(I) Age Band of Subjects	(J) Age Band of Subjects	Mean Difference (I-J)	Std. Error	Sig.[a]
Young	Medium	4.004*	.783	.000
	Old	4.733*	.783	.000
Medium	Young	-4.004*	.783	.000
	Old	.729	.783	.356
Old	Young	-4.733*	.783	.000
	Medium	-.729	.783	.356

Based on estimated marginal means

Pairwise Comparisons

Dependent Variable: Unfiltered RT Ave

(I) Age Band of Subjects	(J) Age Band of Subjects	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Young	Medium	2.435	5.573
	Old	3.163	6.302
Medium	Young	-5.573	-2.435
	Old	-.841	2.298
Old	Young	-6.302	-3.163
	Medium	-2.298	.841

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Unfiltered RT Ave

	Sum of Squares	df	Mean Square	F	Sig.
Contrast	259.725	2	129.862	21.196	.000
Error	330.839	54	6.127		

The F tests the effect of Age Band of Subjects. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

4. Experimental or Control Group * Age Band of Subjects

Dependent Variable: Unfiltered RT Ave

Experimental or Control Group	Age Band of Subjects	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Control	Young	7.692	.783	6.123	9.261
	Medium	5.674	.783	4.105	7.243
	Old	4.547	.783	2.978	6.117
Dyslexic	Young	13.904	.783	12.335	15.474
	Medium	7.915	.783	6.345	9.484
	Old	7.584	.783	6.015	9.153

APPENDIX F7

Anova Tables for Speed of Addition

Univariate Analysis of Variance

Warnings

Post hoc tests are not performed for Experimental or Control Group because there are fewer than three groups.

Between-Subjects Factors

		Value Label	N
Experimental or Control Group	0	Control	30
	1	Dyslexic	30
Age Band of Subjects	1	Young	20
	2	Medium	20
	3	Old	20

Descriptive Statistics

Dependent Variable ADD1P2RT

Experimental or	Age Band of Subjects	Mean	Std. Deviation	N
Control	Young	9.1400	1.2849	10
	Medium	7.9747	1.6989	10
	Old	6.6580	.7361	10
	Total	7.9242	1.6247	30
Dyslexic	Young	13.9393	2.4995	10
	Medium	8.9400	1.0328	10
	Old	8.5440	1.5111	10
	Total	10.4744	3.0357	30
Total	Young	11.5397	3.1310	20
	Medium	8.4573	1.4553	20
	Old	7.6010	1.5081	20
	Total	9.1993	2.7351	60

Levene's Test of Equality of Error Variances[a]

Dependent Variable: ADD1P2RT

F	df1	df2	Sig.
2.509	5	54	.041

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+GROUP+AGE+GROUP * AGE

Tests of Between-Subjects Effects

Dependent Variable: ADD1P2RT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	309.260[a]	5	61.852	25.285	.000
Intercept	5077.664	1	5077.664	2075.763	.000
GROUP	97.555	1	97.555	39.881	.000
AGE	171.648	2	85.824	35.085	.000
GROUP * AGE	40.058	2	20.029	8.188	.001
Error	132.093	54	2.446		
Total	5519.017	60			
Corrected Total	441.353	59			

a. R Squared = .701 (Adjusted R Squared = .673)

Lack of Fit Tests

Dependent Variable: ADD1P2RT

Source	Sum of Squares	df	Mean Square	F	Sig.
Lack of Fit	.000	0	.	.	.
Pure Error	132.093	54	2.446		

Estimated Marginal Means

1. Grand Mean

Dependent Variable: ADD1P2RT

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
9.199	.202	8.795	9.604

2. Experimental or Control Group

Dependent Variable: ADD1P2RT

Experimental or Control Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Control	7.924	.286	7.352	8.497
Dyslexic	10.474	.286	9.902	11.047

3. Age Band of Subjects

Dependent Variable: ADD1P2RT

Age Band of Subjects	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Young	11.540	.350	10.839	12.241
Medium	8.457	.350	7.756	9.158
Old	7.601	.350	6.900	8.302

4. Experimental or Control Group * Age Band of Subjects

Dependent Variable: ADD1P2RT

Experimental or Control Group	Age Band of Subjects	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Control	Young	9.140	.495	8.148	10.132
	Medium	7.975	.495	6.983	8.968
	Old	6.658	.495	5.666	7.650
Dyslexic	Young	13.939	.495	12.948	14.931
	Medium	8.940	.495	7.948	9.932
	Old	8.544	.495	7.552	9.536

APPENDIX F8

Anova Tables for Speed of Subtraction

Univariate Analysis of Variance

Warnings

Post hoc tests are not performed for Experimental or Control Group because there are fewer than three groups.

Between-Subjects Factors

		Value Label	N
Experimental or Control Group	0	Control	30
	1	Dyslexic	30
Age Band of Subjects	1	Young	20
	2	Medium	20
	3	Old	20

Descriptive Statistics

Dependent Variable: SUB1P2RT

Experimental or	Age Band of Subjects	Mean	Std. Deviation	N
Control	Young	10.4673	2.2697	10
	Medium	9.1240	2.1882	10
	Old	7.5113	1.2274	10
	Total	9.0342	2.2501	30
Dyslexic	Young	13.9780	2.5504	10
	Medium	10.3973	2.1315	10
	Old	9.6587	1.5466	10
	Total	11.3447	2.8021	30
Total	Young	12.2227	2.9605	20
	Medium	9.7607	2.2016	20
	Old	8.5850	1.7493	20
	Total	10.1894	2.7758	60

Levene's Test of Equality of Error Variances[a]

Dependent Variable: SUB1P2RT

F	df1	df2	Sig.
.889	5	54	.495

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept+GROUP+AGE+GROUP * AGE

Tests of Between-Subjects Effects

Dependent Variable: SUB1P2RT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	230.628[a]	5	46.126	11.121	.000
Intercept	6229.487	1	6229.487	1501.931	.000
GROUP	80.072	1	80.072	19.305	.000
AGE	137.842	2	68.921	16.617	.000
GROUP * AGE	12.714	2	6.357	1.533	.225
Error	223.973	54	4.148		
Total	6684.088	60			
Corrected Total	454.601	59			

a. R Squared = .507 (Adjusted R Squared = .462)

Lack of Fit Tests

Dependent Variable: SUB1P2RT

Source	Sum of Squares	df	Mean Square	F	Sig.
Lack of Fit	.000	0	.	.	.
Pure Error	223.973	54	4.148		

Estimated Marginal Means

1. Grand Mean

Dependent Variable: SUB1P2RT

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
10.189	.263	9.662	10.717

2. Experimental or Control Group

Dependent Variable: SUB1P2RT

Experimental or Control Group	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Control	9.034	.372	8.289	9.780
Dyslexic	11.345	.372	10.599	12.090

3. Age Band of Subjects

Dependent Variable: SUB1P2RT

Age Band of Subjects	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Young	12.223	.455	11.310	13.136
Medium	9.761	.455	8.848	10.674
Old	8.585	.455	7.672	9.498

4. Experimental or Control Group * Age Band of Subjects

Dependent Variable: SUB1P2RT

Experimental or Control Group	Age Band of Subjects	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Control	Young	10.467	.644	9.176	11.759
	Medium	9.124	.644	7.833	10.415
	Old	7.511	.644	6.220	8.803
Dyslexic	Young	13.978	.644	12.687	15.269
	Medium	10.397	.644	9.106	11.689
	Old	9.659	.644	8.367	10.950

Additional Behaviour

G.1 Multiplication Findings

This is an account of behaviour and actual words spoken by participants during the testing. Each participant has been given a number:

D1 – D10	Young dyslexics
C1 – C10	Young CA controls
S1 – S10	Young SA controls
D11 – D20	Medium-age dyslexics
C11 – C20	Medium-age CA controls
S11 – S20	Medium-age SA controls
D21 – D30	Old dyslexics
C21 – C30	Old CA controls
S21 – S30	Old SA controls

Only observations that are of relevance to this research have been included in this section. Notes were taken, where necessary, by the researcher during the testing of individual participants on both trials. There are some instances where the participant typed in part of an answer (only one digit) and then realised the error and called out the correct answer. These instances are recorded and are placed under the category 'Other Audible Vocalisation'. The figures in brackets in this category (in Table G1) refer to comments like, 'Oh no' that are said in addition to any adjusted answer.

D1 9 times table finger technique, '$1 \times 9 = 9$, $2 \times 9 = 18$, $3 \times 9 = 72$' (27 backwards), verbalising, waving hands above keys, sighing, liked to check the screen to see if his answer had been typed in correctly, $5 \times 8 = 4$, $2 \times 9 = 16$ 'Oh no its not', $1 \times 4 = 3$ 'Oh got that one wrong . . . 4'.

D2 verbalising on every question, 'useless' at the 9 times table, 'I tend to get numbers the wrong way around', for example $2 \times 8 = 61$, $6 \times 2 = 21$, $7 \times 2 = 41$, $2 \times 9 = 81$, 4×3 . . . 3×4, 'Its gone. I just had it. I keep thinking its divide', use of fingers for the 2 and 5 times tables, 5×5 'Is ten I think' and then used fingers = 25, $1 \times 11 = 11$ 'I could hardly get that one back to front', searching for keyboard numbers and then checking up on the screen to see if the numbers have been typed the wrong way around . . . (quite a demanding task), talking to researcher in the middle of a question – about his mother's computer.

D3 use of fingers, 9 times table finger technique, $6 \times 4 = 21$ 'Oops, supposed to be 24', $2 \times 1 = 1$ 'Supposed to be 2', approaches keypad with a flat hand/index finger, mouthing.

D4 verbalised, 3×2 'two threes are six', $3 \times 10 = 53$ 'I wanted 30', 'I have a bit of trouble with my 4's as well. I'm not very good at them', use of fingers, unsure of the 5 times table for counting up on the fingers, $5 \times 5 = 10$ (adding perhaps), 2×8, participant suddenly jumped forward as though the answer had just struck him but it was a 'Miss' (took over 22 seconds).

D5 use of fingers, verbalising, '8×4 . . . 4×8', $9 \times 2 = 81$, $3 \times 6 = 81$, $8 \times 2 = 61$, 8×4 'two eights sixteen, three eights twenty-four, four eights thirty-two', adopted the same approach for 9×4 but went past onto 'Five nine's are . . .' without realising, searching for keys, 4×10 . . . stared at screen and then said, 'Of course' and typed in 40.

D6 use of fingers, verbalised, $10 \times 9 = 99$ 'Oh no it's 90', 8×12 displayed and participant said '12×8', 9×12 . . . 'Twelve tens are . . .? I don't know'.

D7 fingers for the 1 and 5 times tables, passed on questions in the 10 times table, $9 \times 1 = 6$ 'Oops I wanted 9', 9×3 ' Is that nine threes?', verbalising, use of fingers for 5×5 which came to 30, tends to carry on working out the answer to a previous question (perseverating), relying heavily on his fingers to count up in ones, 'Oh bother', decides to 'Pass' on 'hard' ones after consulting fingers, 12×3, started counting up in 3s and 'forgot' where he was up to, 8×5 . . . '5, 10, 15, 25, 30, 35, 40, 45' 'Oh drat!', 'I don't know my birthday (aged 10:7 years) but I know my address'.

D8 verbalising, fingers, running up the tables laboriously, participant wanted to answer some of the missed questions in the interval, 'Passed' on 5×9 and participant thought the question was a 'hard' one and on first seeing it he pressed the "Enter" key. Then he realised that he could answer it (45).

D9 mouthing (a shy participant), fingers, $3 \times 2 = 3$ 'Oh I wanted 6'.

D10 mouthing, fingers, $2 \times 10 = 5$ . . . 'Meant to be 20', $9 \times 9 = 88$ . . . 'Oh I meant 89'.

Medium-age Dyslexics

D12 A lot of itches on legs, head, neck, wrist, nose, comment – 'Nothing came [into my head] and then I remembered $9 \times 9 = 81$ and subtracted', $3 \times 5 = 45$ . . . then said answer correctly.

D13 use of fingers, hand over mouth, liked to cover nose and mouth to think, running fingers through fringe, yawning, tended to 'Miss' quite a lot, had afterthoughts, which he called out, $11 \times 7 = 81$ – not very familiar with the 11 times table.

D14 6×8 'Oh no', 'Do they repeat themselves?', hand over mouth, verbalising, 'Oh not again', 7×9 – said answer first and then typed it in . . . $7 \times 4 = 7$ . . . then said correct answer, gets stuck in a thought, uses the 5 times table as a basis on which to work out 7×6 ($7 \times 5 = 35$), 7×12 . . . '70, that's 14 = 84', $9 \times 6 = 64$ . . . 'Oh it's 54' was said two questions later, $12 \times 7 =$ '70, 70, 70, 84', tends to continue to work out previous questions after they have gone from the screen (is perseverating).

D15 'I think that I made a few muck ups', moving around a lot, adjusting glasses, sniffing, scratching, 2×9 . . . 'Two nines are eighteen' and then typed it in, 1×7 . . . stared at screen, 'I'm rushed. If I had more time I could work it out . . . I get muddled up', puts hand to mouth in between each question, $5 \times 5 = 10$.

D16 looking around for keys, varying which hand types in the response, 3×10 . . . participant repeated the question 2 times, a lot of body and hand movement, fingers are a bit clumsy on the keypad, rubs nose after every answer, tended to think about the previous question, 'Oh no, I've made a mistake', 'I'm faster today', $3 \times 8 = 24$ 'I don't know what took me so long about that', verbalising, $9 \times 12 = 180$ 'Oh God, that was supposed to be 108', 'I think that I might have done better this time', $7 \times 6 = 42$ 'No, its supposed to be 46 . . . 44', $12 \times 1 = 21$ 'Oh that's supposed to be 12'.

D17 verbalising, $8 \times 12 = 72$ even though participant said '96', 'I should be able to delete', 'What is the difference between doing this orally and doing this on the computer?' $5 \times 3 = 55$ ('15' said as an afterthought), $8 \times 6 = 24$ . . . then said correct answer.

D18 fingers, verbalised, sighing, for 2×7 the participant's finger hovered over the '4' key first and he then pressed 14 (fourteen sounds as though it starts with a 4), mouthing, making immediate decisions, for example, to pass on questions from the 9 and 12 times tables.

D19 verbalised, $10 \times 11 = 100$ 'I want 110. Oh flip', $11 \times 10 = 101$ 'Oh, I've done it again, 110 again', use of fingers, $10 \times 10 = 110$ 'This time', $10 \times 2 = 10$ 'Oh no, 20', $11 \times 10 = 100$ 'Oh no, 110', $2 \times 2 = 2$ 'Oh no, it's 4', said that his mind was full up and he found it hard to move with a clear mind onto the next question.

D20 verbalising on the ones he has to think about, fingers, $3 \times 9 = 26$, $9 \times 5 = 54$, $10 \times 10 = 11$ 'Oh, that's supposed to be 100', cautious key pressing, slow and deliberate.

Old Dyslexics

D21 questionable manual dexterity due to some accidental passes, spends longer than the controls to register the question on screen, on 9×3 closed eyes to think, fingers in the air at times, 'Only half way!', $8 \times 6 = 8$, said correct answer afterwards.

D22 $3 \times 7 = 22$, $7 \times 2 = 4$, $1 \times 3 = 6$, $6 \times 10 = 9$ . . . said correct answers after each attempt.

D23 waving fingers, $12 \times 6 = 6$, $8 \times 1 = 9$ ('Oh!'), $6 \times 7 = 43$, $9 \times 10 = 9$, $2 \times 1 = 3$, $5 \times 5 = 55$ ('Oh') . . . then said correct answers after each attempt,.

D24 started pressing in some of the answers incorrectly in his haste and then said the correct answer, $12 \times 9 = 80$, $3 \times 9 = 1$, $3 \times 10 = 2$, $11 \times 11 = 11$ . . . then said correct answers after each attempt, on 6×4 said, 'Oh God' under his breath as if indicating that he should know it, moves feet around a lot in between questions, types in the first digit and then thinks.

D25 finger method for the 9 times table, this is a fast method and well used, uses fingers for 3 and 4 times table questions, $6 \times 7 = 6$, $3 \times 12 = 4$, $8 \times 8 = 38$ . . . then said correct answers after each attempt, many errors in answers.

D26 mouthing the questions and the answers (not audible), $6 \times 3 = 3$ . . . then said correct answer, sometimes thinks his right answer is wrong.

D27 verbalises while working out, breaks up larger questions into smaller ones, for example 9×12 was worked out as $9 \times 10 = 90$ and $9 \times 2 = 18$ and the two products added together. 'Everything seems to hinge on 36.' Stared at screen on 10×6, said the answer and then responded by typing it in, 5×5 = '55 no 25', 3×3 = '12 no 9', '$3 \times 8/8 \times 3$ = 8, 16, 24', 2×3, pause and then suddenly cottoned on, 7×2 = '18 no 14', 6×12 = '60..72', thinking of the last question – hence he was staring at the screen, verbalised '4×10 are 40', hitting keys fairly heavily and erratically, 8×9 = '$9 \times 9 = 81$ . . . 72', 8×7 = '$7 \times 7 = 41$ . . . 49'. 'I need to go back to bed . . . .I get tired'.

D28 $1 \times 8 = 9$ as though adding! $1 \times 5 = 4$ . . . then said correct answer afterwards, strategy for working out, 'I take it from the one I know and count up from there (an example of the 'anchor point' strategy)', scratched right side of the top of head.

D29 incorrectly responded to 12×6 and said, 'Oops, should be 72', fast but some major flaws in his answers, 'I am slow at thinking', 'The 8 times table is dodgy', asked how long the gap was between each question – thought it was 5 seconds.

D30 $12 \times 7 = 81$, $5 \times 6 = 35$, $6 \times 10 = 5$ . . . then said correct answer after each attempt, $2 \times 1 = 3$ (was participant adding?).

Young CA Controls

C1 using fingers for the 12 times table, $9 \times 10 = 99$ . . . then said correct answer.

C2 fingers on 5×6 only, $12 \times 5 = 5$ . . . said correct answer afterwards, $4 \times 4 = 24$ . . . '16, tut'.

C5 moved head and mouth when working out, $10 \times 9 = 99$ . . .'Oh no, 90', $12 \times 9 = 8$ . . . said 108 much later, 'It's doing the same question over and over again', nodding head.

C6 mouthing but quiet – no sound, $3 \times 6 = 81$, $7 \times 2 = 41$ (reversals) . . . said the correct answer after each attempt, can hear the question under his breath – only just.

C7 use of fingers sometimes, mouthing.

C8 verbalising (just audible), $12 \times 6 = 54$ . . . .said correct answer afterwards.

C9 verbalising, 'Oh no' (8×8), $12 \times 9 = 103$ . . . 'Meant 108'.

C10 some verbalisation, $10 \times 5 = 10$ . . . 'I want 25'.

Medium-age CA Controls

C11 'I don't know my 12s', $5 \times 1 = 4$, said correct answer afterwards, 'What happens if you make a mistake?', 'We had that before the other way around'.

C12 $6 \times 6 = 39$, $12 \times 10 = 2$, $9 \times 2 = 01$, said correct answers afterwards, 'Why are some questions asked again?', scratching right ear.

C13 $6 \times 12 = 24$, $7 \times 5 = 4$, said correct answers afterwards, 'I can see that I have already made one mistake'.

C14 $5 \times 7 = 2$, $6 \times 3 = 19$ ('Ah'), said correct answers after each attempt, tends to stare at the questions for a length of time, appears slow to process information visually.

C15 When answer is well known the correct numbers to press are sought out fast, $5 \times 3 = 41$, then said correct answer.

C16 $4 \times 7 = 27$ 'Oh, 28', use of fingers even for 5×5, often has to work out an answer.

C17 searching for the keys, $7 \times 7 = 46$ 'Oh drat' said under breath, 'Oh no', 9 times table finger technique.

C18 $11 \times 1 = 1$ 'Oh', $5 \times 5 = 55$ laughed, 'I wanted 25', 'Can I delete?', gentle approach – doesn't race to the "Enter" key but has a rhythmical approach, $7 \times 7 = 45$, $9 \times 5 = 50$, then said correct answers after each attempt.

C19 $3 \times 6 = 2$, $5 \times 7 = 4$ . . . said correct answers afterwards, verbalising, moving index finger and second finger up and down like scissors, is 12×4 seen as the same as 4×12?

C20 $4 \times 7 = 3$, $6 \times 1 = 3$, $9 \times 7 = 61$, said correct answers to these after each attempt.

Old CA Controls

C20 $3 \times 12 = 6$ then said correct answer afterwards.

C21 showed dismay, $6 \times 7 = 3$ said correct answer afterwards.

C22 $6 \times 9 = 45$, $12 \times 4 = 6$, said correct answer after each attempt, varied style – quick at times and then gentle.

C23 $8 \times 8 = 56$, said answer correctly afterwards.

C24 $11 \times 2 = 1$, $9 \times 9 = 75$, $12 \times 7 = 87$, $3 \times 11 = 3$, said correct answers after each attempt.

C25 verbalising on some, very little knowledge on the 12 times table at the higher end, $8 \times 7 = 59$, $9 \times 5 = 5$, $8 \times 2 = 8$, then said the correct answers.

C26 'What's the answer? OK.'

C27 'Can I press delete?', $5 \times 9 = 40$, $11 \times 10 = 111$, then said correct answers, pressing fast.

C28 'Transferring thoughts onto keys takes time', on 12×1 participant stared at screen for a long time then blinked and shook his head, calling out correct answers after he had responded incorrectly.

C29 only looks at screen for a fraction of a second, $6 \times 5 = 35$, said correct answer afterwards, 'I made mistakes on the 8 times table'.

C30 for 7×3 typed 15 and said, 'Oops, wrong one!'

Young SA Controls

S1 verbalised.

S3 $12 \times 9 = 100$, said 108 afterwards.

S4 verbalising, $4 \times 12 = 49$, said 48 afterwards.

S6 fingers.

S7 fingers, verbalising.

S8 slight verbalisation.

S9 verbalising.

S10 fingers, verbalising, 4×12.'Supposed to be 48', said about 20 seconds later.

Medium-age SA Controls

S11 verbalising.

S19 fingers, saying and hearing own voice – answer came from speaking.

Old SA Controls

S23 $7 \times 5 = 30$, $3 \times 3 = 3$, said correct answer after each attempt, 'I'm not very good at the 12 and 4 times tables, after typing in an incorrect answer the participant then called out the right answer.

S25 $2 \times 4 = 4$, $2 \times 6 = 18$, said correct answer after each attempt, 'Oh no'.

S26 $11 \times 3 = 63$, $6 \times 3 = 19$, said correct answer after each attempt, $7 \times 8 = 3$, $12 \times 9 = 103$, said correct answer after each attempt, $9 \times 9 = 18$.

S28 silent operator, seems quite competent.

S29 'I made a mistake' . . . 'That was 72'.

S30 $8 \times 7 = 47$, 'Oops, I've done something wrong. It was supposed to be 48', 5×9, said 45 afterwards.

It was decided to group these outward behaviours into four categories:

(1) 'use of fingers' as a way of working out the answers;

(2) 'other bodily movements' if participants moved parts of their body overtly as compared to sitting quietly without any undue movement over and above the requirements of the experiment;

(3) 'audible vocalisation as an aid', for example where the participant repeated the question out loud or sub-vocalised when working out the answer;

(4) ‘other audible vocalisation’, which included any comments or observations made about the experiment while in progress or any ‘Oh no’ type comments, including big sighs or a particularly deep breath.

A tally was made of these behaviours and is expressed in Table G.1. Similar tallies of the four categories of behaviour are presented in Tables G.2, G.3 and G.4 for the other operations.

Table G.1 Observations of four categories of additional behaviour made during the Multiplication experiment

		Use of fingers	*Other bodily animation*	*Audible vocalisation as an aid*	*Other audible vocalisation*	*Total*	*Group total*
Dyslexics	Young	19	8	14	17 (9)	58	123
	Medium-age	5	8	12	16 (7)	41	
	Old	2	5	2	15 (7)	24	
CA controls	Young	4	4	4	11 (3)	23	62
	Medium-age	2	3	1	17 (8)	23	
	Old	0	2	1	13 (6)	16	
SA controls	Young	5	0	10	3 (0)	18	32
	Medium-age	1	0	3	0 (0)	4	
	Old	0	0	0	10 (4)	10	
Total		38	30	47	102	217	

Observations on Multiplication

The reason for the fourth category (‘other audible vocalisation’) having a higher tally than on the operations was because the participants in this experiment were given instructions to call out their amended answers because the delete key was not functional. The instructions were adjusted for the other operations as an improvement, since it was thought that this request might distract the participants from the task at hand.

G.2 Division Findings

This is an account of behaviour and actual words spoken by participants during the testing. Each participant has been given a number, which remains the same for the Addition Findings (G.3) and the Subtraction Findings (G.4):

D1 – D10	Young dyslexics
C1 – C10	Young controls
D11 – D20	Medium-age dyslexics
C11 – C20	Medium-age controls
D21 – D30	Old dyslexics
C21 – C30	Old controls

Only observations that are of relevance to this research have been included in this section. Notes were taken, where necessary, by the researcher during the testing of individual participants.

Young Dyslexics

D1 putting elbows up on the carpet base, saying each question, 9 times table finger technique, use of fingers (for example on $8 \div 4$), 'I should know my 6 times table', $25 \div 5 =$ (counting and using fingers '5, 10, 15, 20, 25') '5', $30 \div 5 = 6$ 'I just hope it is!' 4 times table performed on fingers, $42 \div 7 =$ said '5' but typed 6.

D2 saw the question $108 \div 9$ and choked jokingly (indicating that this question was hard for him), used fingers for $60 \div 5$ and timed out since this took longer to answer than the allotted 22 seconds, stated that division was the easiest of the four operations and that he hardly knew his tables, leaning head on hands at times.

D3 verbalised ('33 ÷ 3, how many 3s in 30?'), 'some of these are pips (easy)', use of 9 times table finger technique on division, stated that the hardest division tables were 12, 6, 7 and 8.

D4 in response to a division question said, 'You must be kidding. How am I supposed to know this one?' chatting away, moving mouth, making mouth noises, easily distracted by his thoughts, 'My arm needs a rest'.

D5 verbalised, use of fingers, 'Oh flip', asked 'Am I over half way?' didn't seem to know the answers to many of the questions but guessed.

D6 showing little understanding of what division entails.

D7 laying head down on arm, verbalising, foot moving up and down, rolled up sleeves, rhythmical tapping.

D8 lacking consistency, use of fingers, foot jiggling rhythmically.

D9 was unsure of 22 ÷ 2, but answered 11 eventually.

D10 yawning, eye rubbing, a lot of arm movements, massaging cheeks, forehead and temples, hunched over keys and then straightening out, 'Oh no!'

Medium-age Dyslexics

D11 50 ÷ 5 used fingers, not sure of 70 ÷ 7, for 14 ÷ 2 counting up in 2s.

D12 response to 88 ÷ 11 said, '11 times something . . .' The 12 times table is the hardest from 6 × 12 to 9 × 12, 'I practise a lot at home [on division/multiplication facts] with mum once a week'.

D13 quiet.

D14 verbalising, use of fingers for the 5-division table, counting up in 4s to reach the answer for 28 ÷ 4, use of fingers for 14 ÷ 2, use of 'Gypsy' method which is a strategy of using the fingers in a particular way to work out an answer.

D15 'Oh no!' – at age 7 years his work went downhill in previous school.

D17 quiet, a good listener who responds by nodding appropriately to directions given.

D18 resting chin on upturned hand, verbalising, 'Oh no . . . drat', use of fingers on the 2 times table questions, strategy of running up the multiplication tables to find an answer, 60 ÷ 12 said, 'How many 12s in 60?'

D19 was swinging legs, moving mouth and jaw, lot of movement, hands moving over keys, feeling his hair, sniffing.

D20 sighing.

Old Dyslexics

D22 'I hate division' (said very sweetly), big inhalation with a difficult question as though working up to making a decision (as to whether to pass etc.), finger tapping, 132 ÷ 12 (gave a small laugh), toes feeling the table leg (in between the big toe and the next toe).

D23 '132 ÷ 11 is particularly hard'.

D25 toe feeling table leg.

D26 much verbalisation, use of fingers for the 2 and 5 division tables, gave a big sigh for 132 ÷ 11, working really hard, feeling the black tape used around the base for the number pad.

D27 deep breath, took off jumper, had afterthoughts about some of the questions.

D29 said the question sub-vocally, on a few occasions quietly vocalised the answer (often the correct answer) that he would have liked to give to a previous question.

D30 'I'm really bad at division', gave the answer 4 to the question $8 \div 4$, clear on some questions and not so on others, long pauses for working out.

Young Controls

C1 verbalising quietly – only speaks the question and not the working out or the answer, sometimes doesn't finish speaking the question if he knows the answer quickly.

C3 used the 9 times table finger technique.

C6 mentioned that the 8 times table is the hardest of the tables.

C10 used the 9 times table finger technique, used fingers on $72 \div 6$ and then passed.

Medium-age Controls

C12 used the 9 times table finger technique.

C16 afterwards in discussion said that the hardest question was $132 \div 11$.

C14 tapping fingers.

C20 sub–vocalizing.

Old Controls

C21 used 6×5 as an anchor point for $42 \div 6$.

C22 very quick, not sure of 132 ÷ . . .

C25 sitting upright and very still, saying some questions on the 8 and 12 division tables under breath.

C30 '144 ÷ 12 is 12 times what?'

A tally was made of the four categories of behaviour. This is presented in Table G.2.

Table G.2 Observations of four categories of additional behaviour made during the Division experiment

		Use of fingers	*Other bodily movements*	*Audible vocalisation as an aid*	*Other audible vocalisation*	*Total*	*Group total*
Dyslexics	Young	5	6	5	6	22	44
	Medium-age	3	2	3	3	11	
	Old	1	3	2	5	11	
Controls	Young	2	0	1	1	4	10
	Medium-age	1	1	1	1	4	
	Old	0	0	2	0	2	
Total		12	12	13	16	53	

G.3 Addition Findings

Young Dyslexics

D1 'I thought we had had lunch already', verbalising on every question and when working out the answer, sitting up then dropping down on hard questions, 'None go over 100', 'Some of these are repeating themselves'.

D2 'I know on 2 questions where I have made a mistake', fingers, 'Instead of pressing 61 I pressed 91', fidgeting with number pad, lot of long blank stares at screen, 'Asking me the same question again'.

D3 verbalising, using fingers about 98% of the time, legs jiggling, echoing the question and working out loud, 45 + 4 'Oh that's easy' (said after about 15 seconds), needed time to log into the question, 'Can't they put one number above another?'

D4 fingers, 'You're right, the delete key doesn't work', 'I was trying to work it out in my head but it went' (timed out), '6 and 7 are nearly impossible to add', (referring to the carpet base) 'I think this is a bit like the carpet we had in our old house', 'How much more?' inconsistent with attention and timing . . . 'I wonder what's for tea?'

D5 sub-vocalising, use of fingers.

D6 'Oh no', fingers.

D7 verbalising, no sock on right foot.

D8 sighing, foot tapping.

D9 fingers, lifting the number pad, 'Can you type in three numbers?'

D10 fingers, verbalising, tutting, sighing, maintaining pace, resting hands on head.

Medium-age Dyslexics

D11 use of fingers, foot moving, 'How long will questions stay?' 'How many questions are there?' 'If I get one wrong – what will happen to the screen?'

D12 fingers.

D14 – verbalising for each one, ‘Come on’, both hands on temples, finger tapping.

D15 verbalising, fingers moving, tapping, sighing, stretching, ‘Oh no’.

D16 verbalised.

D18 verbalising, fingers, tutting, sighing, shaking head.

D19 lifting up keypad, ‘damn’ when typed wrong first digit, waving hand back and forth while working out and looking for the number to press, sighing, tapping fingers, foot waggling, yawning, rubbing eyes.

D20 verbalising, ‘What happens if you slip the keys – does it matter?’ sighing.

Old Dyslexics

D21 saw 37 + 46 and gave out a whistle.

D22 fingers, ‘It’s long’ (referring to the testing).

D23 hand poised, slightly shaking, ‘I got the wrong one which is disgraceful’.

D24 hand to chin, on the hard questions participant typed in the tens first to release memory for the working out of the ones, ‘It is a pity you can’t delete’.

D25 ‘You can’t delete can you?’

D26 ‘I don’t like adding up without a calculator’.

D28 researcher indicated when ten questions were left (‘ten left’) and the participant thought that ‘turn left’ had been said.

D29 verbalising, eye rubbing, neck moving, hand tapping, tutting, clearing throat, scratching side, feeling the number pad and moving it around.

D30 fingers (for example on 61 + 4), verbalising.

Young Controls

C1 verbalising.

C2 fingers on 57 + 38.

C3 fingers.

C4 verbalising, leg moving.

C6 verbalising, sighing, legs waggling, pointing to the screen to work out the HARD sums.

C7 fingers.

C9 verbalising.

Medium-age Controls

C13 verbalised under his breath, going really fast, putting all effort in, 'I am reacting too soon – jumping the gun – and pressing the wrong keys because of it'.

C14 use of fingers, verbalising.

C16 fingers used briefly, verbalizing under his breath, trying hard.

C18 'My brain kept up with it'.

C19 'I was beginning to lose concentration towards the end with the numbers', 'Oh sugar', left index finger on mouth, use of fingers.

C20 use of fingers, verbalising, movement of whole body.

Old Controls

C25 verbalising.

A tally was made of the four categories of behaviour. This is presented in Table G.3.

Table G.3 Observations of four categories of additional behaviour made during the addition experiment

		Use of fingers	*Other bodily movements*	*Audible vocalisation as an aid*	*Other audible vocalisation*	*Total*	*Group total*
Dyslexics	Young	7	6	5	8	26	59
	Medium-age	3	5	5	6	19	
	Old	2	3	2	7	14	
Controls	Young	3	2	4	1	10	23
	Medium-age	4	2	4	2	12	
	Old	0	0	1	0	1	
Total		19	18	21	24	82	

G.4 Subtraction Findings

Young Dyslexics

D1 hands raised in the air, waves of good and not so good despite perseverance, suddenly wakes up, using the number key pad to count back on to get an answer, verbalising each question, 'It's easier with the adding', 'No', shook head, 'No it isn't 40', fingers, 86 – 37 . . . 'You can't do that . . . what if you can't do that?', 'Um, good', gulp, 'I hate maths', interference of numbers from previous question, i.e. 53 – 7 was said as 52 – 7 (where the previous question had been 29 – 2, 'Does it go over the ones again that you haven't done?', 59 – 8 said 69 – 8 (was holding onto 60 something as the answer to the previous question), 87 – 3 used fingers.

D2 'Will there be a trick question like 6 – 79?' putting a lot of effort in to get the brain working, 'I don't listen and drinks wake me up', fingers.

D3 verbalising, jumping leg movement, asking questions and making observations, 'Some of these are easy and others aren't', feeling the carpet.

D4 verbalising, 'I got that last one wrong', 'Let me know when I am half way', 'How long until 10 left?'

D5 fingers, sub-vocalising, sighing, 'How many more have I got?' (after 75% of the way through).

D6 was quiet, hardly moved his body – was immobile, tense shoulders, 38 – 2 = 37, 29 – 8 = 22, taking a long time.

D7 fingers, 54 – 2 was registered as 52 – 4 = 48.

D8 hand to mouth on several occasions, passing on the HARD items, fingers for example on 24 – 3.

D9 'How many questions are there?' Head resting on arm on carpet, playing with skin on his hand.

D10 slow movements and sighing, 'Oh no', leaning on carpet, head low, worked very hard, worked out 95 – 58 by '(tens) 5 add on up to 9 = 40, 5 from 8 = 3, 40 – 3'.

Medium-age Dyslexics

D11 fingers.

D12 addition is easier than subtraction because one can imagine the sum visually one above the other and it is also quicker.

D14 verbalising – repeating number out loud to hold onto it in memory, fingers, 'Oh come on . . . I can do this – easy', worked out 51 – 28 by adding 28 + 2 = 30 then adding 20 and then 1.

D15 verbalizing the question, sighing.

D16 'Is the research to do with working out who is dyslexic?'

D18 rolled up sleeves, verbalising even as typing in answer, fingers for example on 49 – 7, slapping thigh, lot of sighing, a big effort, saw 54 – 27 and said 'Oh no, not these', worked out HARD type questions by visualising the numbers one above the other in his head.

D19 sighing, exploring and feeling the keys, worked out 83 – 48 by 'taking 4 from 8 = 40, 8 – 3 = 5, 40 – 5', subtraction was the easiest and division was the hardest.

D20 worked out 82 – 56 by '8 – 5 (tens) = 30 and 2 – 6 (ones) = – 4 therefore the answer is 26', sighing.

Old Dyslexics

D21 worked out 97 – 68 by '(ones) 7 – 8 = –1, (tens) 90 – 60 = 30, 30 –1 = 29'.

D22 perseverating, worked out 73 – 36 by '(ones) 3 – 6 = –3, 70 – 3 = 67, 67 –30 = 37'.

D23 worked out 82 – 56 by 'going 56 up to 60, 82 – 60 = 22, knock 4 straight on = 26'.

D24 worked out 83 – 48 by '(tens) 8 – 4 = 40, 43 – 8 = 35'.

D25 worked out 73 – 36 by '(ones) 3 – 6 gives a difference of 3, (tens) 7 becomes 6, 6 – 3 = 3, other ten left over take away 3', when asked by researcher how his brain felt, participant said 'tired'.

D26 'It is quite long . . . I don't like mental maths', worked out 51 – 26 by thinking '5 – 2 = 30, go into the 20s, then 1 – 6'.

D27 the participant thinks of novel ways of approaching his maths – ways that his teacher may not have taught him, he says that he gets confused sometimes, worked out 84 – 28 by '(tens) 8 – 2 = 6, 50 something, 8 + 2 + 4'.

D28 worked out 97 – 68 by taking '60 from 90 and then 7 from 8 = 31'.

D29 verbalising, lifting number pad, tilting head, itching centre of back, worked out 73 – 36 by '(tens) 7 – 3 = 4, (ones) 6 – 3 = 3 over, put 4 down to 37'.

D30 fingers, worked out 92 – 47 by '47 + 3 = 50, 30 up to 90, then add 2'.

Young Controls

C3 fingers, worked out 94 – 56 by '(tens) 9 – 5 = 4, (ones) 4 – 6 = 2 left, therefore 42, found addition the easiest and division the hardest.

C9 worked out 84 – 28 by 'adding 60 (to the 28) to make 88, taking 4 from 60', worked out 83 – 48 by 'adding 40 (to the 48) to make 88, I took 8 from 3 which is 5, and took that away from 40 to get 35'.

C10 86 – 37 worked out by going from 37 up to the nearest 10 and then adding up to 80 and then adding on 6.

Medium-age Controls

C11 worked out 97 – 68 by '90 – 60 = 30, 7 (17), 17 – 8 = 9, = 39'.

C14 fingers, foot jiggling, small amount of vocalisation, finger tapping.

C15 worked out $9\underline{7}$ – 68 by '90 – 60 = 30, $3\underline{7}$ – 8'.

C16 HARD strategy – take away the tens first and then the ones.

C17 61 – 27 worked out by counting from 27 to 30 and working it out from there.

C19 fingers.

C20 fingers, verbalising the answer ready for typing in, echoing the question, worked out 83 – 48 by '(tens) 8 – 4 = 4, (ones) 8 – 3 = 5, answer is 45'.

Old Controls

C21 worked out 83 – 48 by '83 – 40 = 43 then –8'.

C22 worked out 83 – 48 by '(tens) 8 – 4 = 4, compare the ones which is five less, equals 35'.

C24 worked out 73 – 36 by '73 – 6 = 67, –30 = 37'.

C25 worked out 73 – 36 by '70 – 30 = 40, take away 3, 40 – 3'.

C26 worked out 83 – 48 by '83 – 8 = 75, 75 – 40'.

C27 worked out 83 – 48 by 'visualising the sum and borrowing in my head'.

C28 worked out 94 – 56 by '(tens) 9 – 5 = 4, 44, 44 – 6'.

C29 worked out 75 – 46 by '15 over the 6 = 9, 7 – 1 = 6, 6 – 4 = 2' (29 is the answer).

C30 worked out 94 – 56 by 'take the 4 and add it to 56 to give 60, 90 – 60 = 30, the answer is 30', addition is the easiest and subtraction is the hardest.

A tally was made of the four categories of behaviour. This is presented in Table G.4.

Table G.4 Observations of four categories of additional behaviour made during the Subtraction experiment

		Use of fingers	*Other bodily movements*	*Audible vocalisation as an aid*	*Other audible vocalisation*	*Total*	*Group total*
Dyslexics	Young	5	5	4	7	21	38
	Medium-age	3	2	3	5	13	
	Old	1	1	1	1	4	
Controls	Young	1	0	1	0	2	8
	Medium-age	3	1	2	0	6	
	Old	0	0	0	0	0	
Total		13	9	11	13	46	

The results were further subdivided into age band comparisons between the groups and are presented in Table G.5 and Table G.6.

Table G.5 Chi-squared and Fisher's Exact Test significant levels comparing the groups by age band on Multiplication and behaviour categories

×	*Category of behaviour*											
	A			*B*			*C*			*D*		
	Age band											
	Y	*M*	*O*	*Y*	*M*	*O*	*Y*	*M*	*O*	*Y*	*M*	*O*
Dyslexics compared to SA controls	***	ns	ns	**	**	* (nqs)	ns	**	ns	***	***	ns
SA controls compared to CA controls	ns	ns	ns	ns	ns	ns	nqs	ns	ns	<u>*</u>	<u>***</u>	ns

Key:

Significance levels

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

(nqs) = not quite significant on Chi-squared.

<u>*</u> / <u>***</u> = indicates that the CA controls showed more of the behaviours than the SA controls.

In all cases where there was a significant difference the dyslexics showed more of the behaviours than the SA controls.

Table G.6 Chi-squared and Fisher's Exact Test significant levels comparing the dyslexic and control groups by age band on operation and behaviour categories

Operation	*Category of behaviour*											
	A			*B*			*C*			*D*		
	Age band											
	Y	*M*	*O*	*Y*	*M*	*O*	*Y*	*M*	*O*	*Y*	*M*	*O*
×	***	ns	ns	ns	ns	ns	**	***	ns	nqs	ns	ns
÷	ns	ns	ns	*	ns	ns	ns	ns	ns	nqs	ns	*
+	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	**
–	ns	ns	ns	*	ns	ns	ns	ns	ns	**	*	ns

Key:

Significance levels

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$

Y = young age band
M = medium age band
O = old age band
nqs = not quite significant

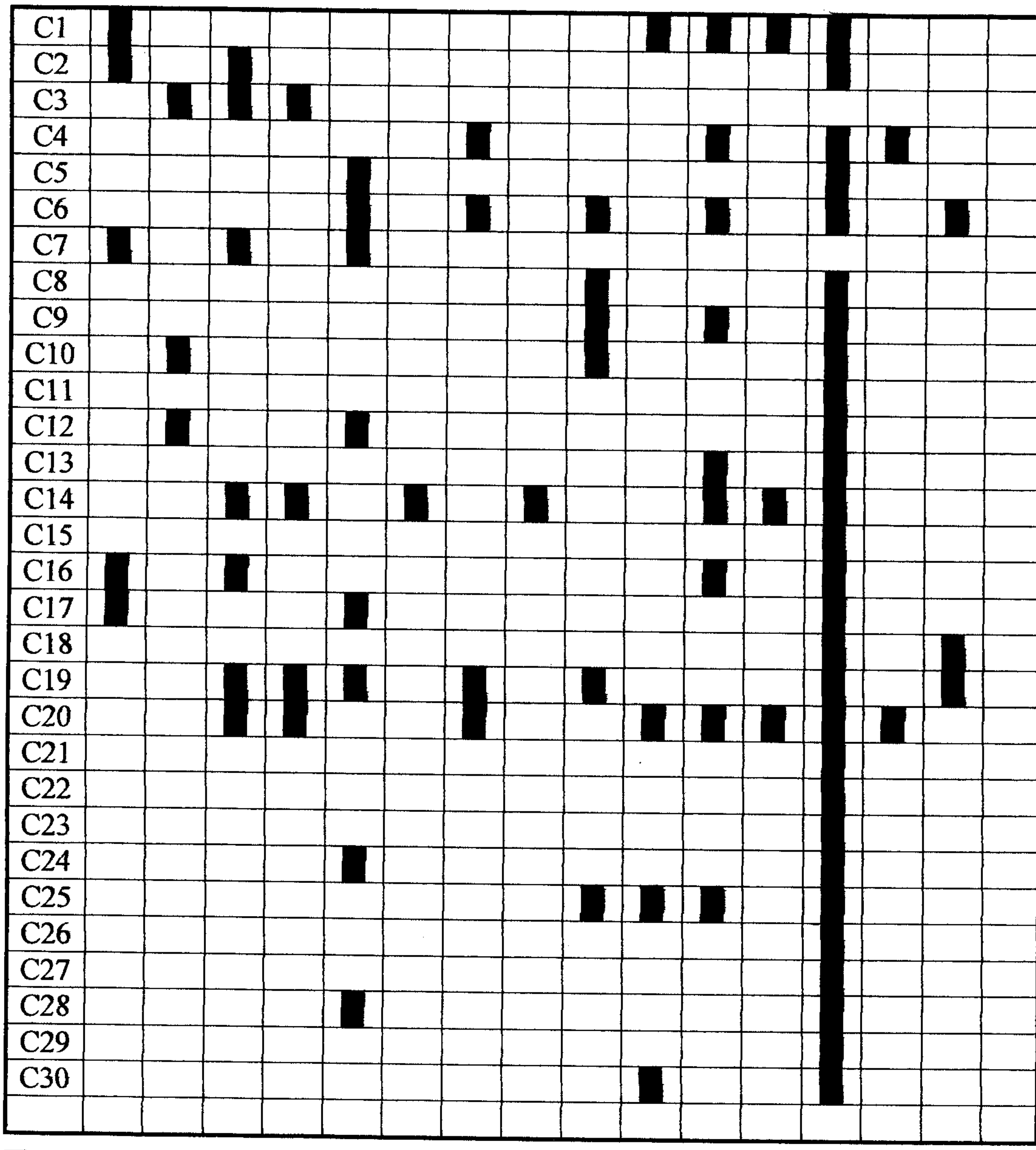
In all cases where there was a significant difference the dyslexics showed more of the behaviours.

<u>APPENDIX H</u>

Additional Behaviour of Individual Participants

Table H.1 Type of classified behaviour made by individual participants by operation

	Category															
	A				*B*				*C*				*D*			
	×	÷	+	−	×	÷	+	−	×	÷	+	−	×	÷	+	−
D1	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
D2	■	■	■	■		■	■		■				■	■	■	■
D3	■	■	■		■		■	■		■	■	■	■	■	■	■
D4	■		■		■	■			■	■		■	■	■	■	■
D5	■	■	■	■	■				■	■	■	■	■	■		■
D6	■		■						■				■		■	
D7	■			■	■	■			■	■	■		■			
D8	■	■		■		■	■	■	■				■		■	
D9	■		■		■			■					■		■	■
D10	■		■		■	■	■	■			■		■	■	■	■
D11		■	■	■			■								■	
D12			■		■					■			■			
D13	■				■								■			
D14		■		■	■		■		■	■	■	■	■		■	
D15					■		■		■		■	■	■	■	■	■
D16					■				■		■		■			■
D17									■				■			
D18	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
D19	■					■	■	■	■				■		■	■
D20	■								■		■		■	■	■	■
D21					■								■		■	
D22			■			■							■	■	■	
D23					■								■	■	■	
D24													■		■	
D25	■					■							■		■	
D26		■			■	■				■			■	■	■	■
D27					■				■				■	■		
D28					■								■			
D29							■	■		■	■	■	■		■	
D30			■	■							■		■	■		



■ = Classified behaviour present

Notes:

1. A different group of participants took part in Stage 1 (Multiplication) to Stage 2 (Division, Addition and Subtraction).
2. Category D Multiplication (Stage 1) – in the instructions participants were informed that they could 'say' an answer if they had not been able to enter their response satisfactorily (since the delete key did not function).
3. A classified behaviour was included as present by combining observations made across two trials where applicable.